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A COMPARISON OF RESIN BONDED PIGMENT, SULFUR AND QUARTERMASTER DEVELOPED VAT DYE FORMULATIONS FOR ACHIEVING INFRARED CAMOUFLAGE ON TEXTILES

Alvin O. Ramsley, Physical Chemist

Basil A. Natsios, Organic Chemist

Jesse D. Ely, Technologist

TEXTILE, CLOTHING AND FOOTWEAR DIVISION

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FRANK J. RIZZO
Chief, Textile Dyeing
and Finishing Laboratory

FOREWORD

The history of research, aimed to meet specific military characteristics, is one of constant compromise. Conflict after conflict results from the achievement of one military characteristic with respect to other desirable and necessary characteristics.

The work which is reported in the following pages is not an exception to this somewhat general situation. In the particular case at hand, faith in an idea has been rewarded by the development of new colorants which are the result of basic research processes aimed at a definite goal. While the results themselves are not all that one could desire, the developments to date are of such a character that there is definite hope of further specific achievement along the same lines in future studies.

The future of such studies is dependent upon the availability of information from the using agencies as to the potential need for colorants with characteristics in the extended range. Within the limitations cited in the report as herewith presented, the threat of the present Sniperscope can be met very adequately without impairing fabric functionability.

Frank J. Rizzo

FRANK J. RIZZO
Chief
Textile Dyeing Laboratory Branch

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A. O. Ramsley, B.A. Natsios, J. D. Ely

GENERAL SUMMARY

Three colorant systems are reported which are capable of achieving specific reflectance values in the spectral range of sniperscope sensitivity which conform to recommendations proposed by the Corps of Engineers. Substantial amounts of fabric were prepared using each of the three colorant systems to obtain visual shades close to the standard for Olive Green 107. The methods described are fundamentally different from each other, namely; a resin bonded inorganic pigment system, a combination of sulfur dyes, and a recently developed vat dye formulation.

In order to evaluate the methods reported, comparisons are made for several characteristics relating to field performance. Experimental data include physical properties, sewability, water repellency, color fastness, infrared reflectance, and resistance to anti-vesicant impregnation.

These data show that the sulfur dyed fabric fails with respect to color fastness and resistance to anti-vesicant impregnation. Both the new vat dye and pigment systems are equally capable of achieving the recommended reflectance values in the spectral region of sniperscope sensitivity. This has been attained without sacrifice in quality with respect to physical properties, sewability, water repellency and color fastness. The recently developed vat formulation shows no improvement over the present standard in resistance to anti-vesicant impregnation. The resin bonded inorganic pigment system, on the other hand, when properly treated with water repellents, far surpasses the standard in this respect and approaches the demanding requirements defined by the Chemical Corps.

Because of unique advantages over the other systems inherent in the resin bonded inorganic pigment system, it is considered the best colorant method yet developed. It provides controlled reflectance throughout the near infrared; it is adaptable to other military shades; it is the only colorant system which shows any resistance to anti-vesicant impregnation. However, the success achieved in extending the spectral range of controlled reflectance with vat dyes and certain observations made in this study on the effect of chemical treatments on spectral properties are encouraging. These observations suggest that studies of dye structure may eventually prove fruitful for the full spectral range in which active, image forming detectors can be expected to operate. The advantage of utilizing dyes rather than pigments lies in the comparative ease with which the fabric can take on other functional finishes.

If anti-vesicant impregnation can be avoided and consideration of camouflage characteristics can be confined to visual and present sniperscope viewing, then it may be considered that two solutions, the new vat dyes and the resin bonded pigments, effectively conclude the present program.

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THE NATURE OF THE PROBLEM BEING EXPLORED:

With the tactical success experienced in recent military engagements using the sniperscope as a weapon in combat, it is apparent that measures must be developed to minimize its effectiveness when used by enemy forces. Since 1946 several approaches to achieving infrared camouflage on textile items have been investigated within the Quartermaster Laboratories and under research contracts. In general, with the exception of sulfur dyes, no single dye system had been found capable of achieving infrared reflectance values in the region of sniperscope sensitivity of 20 ± 5 percent, recommended by the Corps of Engineers [1] for a cold - wet climate. Therefore, the successful approaches have resulted in either blending operations or double coloring systems to obtain the characteristics requisite for proper concealment at night. Among the systems examined have been the blending of pigmented rayons with vat or chrome dyed fibers [2], the use of resin bonded pigments [3, 4] applied over a dyed ground shade, and more recently, in the case of wool, a system of unifiber blending utilizing certain special dyes [5]. Most of the methods which have been worked out pose problems with respect to the application of functional finishes. This is particularly true of the resin bonded pigment systems, although methods have been developed for combining water repellency, fire resistance and color in one basic operation [6].

From the early days of this project, the feeling has existed in this laboratory that modification of the molecular structure of dyestuffs could influence the electronic states in such a manner as to extend the spectral range of relatively low reflectance further into the infrared. Dye systems have the advantage over pigment systems in the comparative ease with which functional finishes may be applied. The lower infrared reflectance of the present vat dyed standard for Olive Green 107, as compared with previous formulations, is evidence of the feasibility of this line of attack. Furthermore, in early 1950 a vat gray having interesting properties became available from one of the dyestuff companies [7]. With these clues and theoretical considerations as a starting point, a research program was undertaken by the Calco Chemical Company under their research contract. This program has been productive of a large number of new dyes with materially improved infrared characteristics [8]. Fundamentally, the modifications introduced into the molecular structure are such as to increase hydrogen bonding and the resonance of the first excited state.

The present study provides a direct comparison on cotton fabrics for physical properties and color characteristics of the most successful solutions to the problem of achieving the infrared reflectance values recommended by the Corps of Engineers. The study is confined to cotton fabrics, because of their use as the outer layer of combat ensembles and are, therefore, somewhat more important than other fabrics. Three colorant systems are compared; resin bonded inorganic pigment formulations applied over a vat dyed ground shade; a formulation of vat dyes

selected from the relatively large number of dyes produced under the research contract with the Calco Chemical Company; and a selected sulfur dye formulation. The particular vat dyes used are practical because their production could be undertaken within a reasonable time using equipment now available throughout the dyestuff industry. The study has two points of reference: the values of reflectance in the spectral range of sniperscope sensitivity recommended by the Corps of Engineers for infrared properties; and the present specified standard for Olive Green 107 for physical properties and color fastness.

To test the feasibility of using the resin bonded pigment system as a production method, this colorant technique is represented by four groups, the products of four manufacturers of pigments, referred to as A, B, C and D. These four companies out of a larger group had previously submitted formulations which had proved satisfactory in laboratory and semi-scale production to meet minimum requirements with respect to colorfastness. The entire series of resin bonded pigmented fabrics considered in this report were produced by the Cramerton Division of Burlington Mills using formulations supplied by the respective manufacturers and under direction of their representatives. To insure that the production conformed to requirements established with respect to visual shade and infrared reflectance, samples were inspected periodically during the four runs by personnel of the Textile Dyeing and Finishing Laboratory.

It is interesting to note in this connection that of the many samples of foreign origin which have been examined in this laboratory, proper infrared reflectance values, by Corps of Engineers standards, have been achieved on relatively few items. Most of the sulfur dyed fabrics of proper visual shade have infrared reflectance values below fifteen percent. A recent study [9] of twenty-six samples of Russian origin showed that only two sulfur dyed cotton fabrics, a wool-rayon blend and a wool-cotton union met the conditions for infrared reflectance recommended by the Corps of Engineers. The wool-rayon blend and the wool-cotton union achieved these results by use of sulfur dyed cellulosic components and a chrome mordant dyed wool.

PROCEDURE OF EXPERIMENTATION PURSUED:

1. The standard Olive Green 107, used as a reference fabric in this study, was vat dyed in accordance with specification for this shade [10]. For the purpose of minimizing the effects of variability of fabric from one lot to another, a secondary reference, vat dyed against the standard, was introduced from the production of the Cramerton Division of Burlington Mills, using the same fabric lot upon which the resin bonded pigment formulations were applied. This fabric was used as the reference for physical properties and color fastness in

this report and is referred to as Standard Olive Green 107. The formulations used in this and all the other colorant systems considered in this report are summarized in Appendix B.

2. The entire production of resin bonded pigmented fabrics was accomplished by the Cramerton Division with the assistance of representatives of the cooperating pigment manufacturers. The vat dyed ground shade was color matched to a standard developed in this laboratory, so prepared that, when topped with the pigment formulations, it would yield a visual shade close to the standard Olive Green 107. Quartermaster personnel were present as observers and to provide on the spot decisions in the event such were required. Total production for each pigment manufacturer, except "C", was approximately five thousand yards of fabric forty-two inches wide.

Manufacturing conditions used throughout the production for all formulations are summarized below:

Equipment	Padder, three roll, 2 rubber, one center steel roll Dryer at 250°F, capacity 35 yards Tenter frame at 325°F, capacity 30 yards Curing oven at 350°F, capacity 93 yards
Expression	Pick-up, 70% wet, 4.5% dry, one dip, one nip at nine tons pressure
Rate	100 yards per minute

Because of a deficiency in the vat dyed ground shade, a slight side to center shading was observed for all fabrics, and during the individual runs the rolls became coated occasionally and had to be cleaned with solvent.

In general, for manufacturers "A" and "B" operation was smooth and production excellent. For manufacturer "D" the carbon black in the bath showed a tendency to "flush" to the surface. This resulted in fabrics a bit darker and duller than standard, although no spotting of the fabric surface occurred. With manufacturer "C" this became a major problem because the carbon black flushed badly and the surface was spotted. The run was interrupted while a modification of the formulation was made, which resulted in some temporary improvement. The run was stopped, however, after only 1,000 yards of the planned total of 5,000 yards had been completed, because of the increase in surface spotting. Subsequent laboratory work on the part of manufacturer "C" has improved his formulation to a point considered satisfactory, although it has not been proven in actual production. One minor defect in all the production was evident in that a dark blotch the size of a twenty-five cent piece appeared periodically. This was the result of a blister on the botton rubber roll of the padder. This is mentioned to emphasize the need for good equipment in the resin bonded pigment system.

It should be stated that the Cramerton personnel operated under instructions from the representatives of the pigment manufacturers and were limited to the pigment formulations supplied. The success of three of the runs shows that competent mill operators with proper equipment are capable of producing satisfactory fabric, if good formulations are used.

The visual shade of the fabrics after treatment with water repellents showed that the production of "A" was a good match to standard. "B" was a bit on the full side of standard but within allowable tolerance limits. "C" and "D" were dark and dull as a result of the carbon black tending to surface. With the exception of the production of manufacturer "C", the entire run is considered successful.

For the present study, samples were taken at four stages of production for most products: (a) the vat dyed ground shade prior to application of pigment formulations, (b) the same after application of the resin bonded inorganic pigments, (c) resin bonded pigmented fabrics treated with a cationic water repellent, and (d) resin bonded pigmented fabrics treated with a resinous water repellent. The Cramerton plant, at that time, was utilizing the cationic water repellent in connection with a contract originating with the New York Purchasing Agency for Olive Green 107 on 9 ounce cotton sateen. Use of the resinous type was introduced because previous studies [11] had demonstrated some superiority of this type among the so-called durable water repellents, particularly with respect to resistance to anti-vesicant impregnation.

3. The special formulation of vat dyes developed under the Calco contract was applied in the Quartermaster laboratories jointly by representatives of the Calco Chemical Company and personnel of the Textile Dyeing and Finishing Laboratory. Dyestuffs used were the product of a small pilot run and the total yardage processed was approximately 170 yards. The application of dyestuff was accomplished by padding using the Gessner Squeeze machine and processed in the usual manner on the jig.

4. The sulfur dyed fabric was prepared by the Textile Dyeing and Finishing Laboratory and was treated with a resinous water repellent. The formulation, developed in this laboratory, was selected from fast sulfur dyes which could produce a shade approximating Olive Green 107 and was applied in accordance with usual procedures for this type of dye.

5. In order to evaluate the fabrics prepared with regard to expected performance under field conditions, the following color fastness tests were undertaken:

<u>Fastness to Light:</u> In the Atlas Fade-O-Meter, Model FDAR, 160 standard fading hours in accordance with Method 5660, Federal Specification CCC-T-191b.

<u>Fastness to Weathering:</u> In the National Weathering Machine for 100 hours in accordance with Method 5671, Federal Specification CCC-T-191b.

Fastness to Mobile Laundering: Thirty cycles using an anionic synthetic detergent in accordance with field procedures.

Fastness to Chlorine Laundering: Twenty mobile laundering cycles using a solution of 0.1% available chlorine as part of each laundering cycle.

Fastness to Alternate Exposure to Light and Laundering: Exposure for ten hours in the Atlas Fade-O-Meter, Model FDAR, followed by mobile laundering using an anionic synthetic detergent. Evaluations are based on five repetitive cycles.

6. Color changes in the various fastness tests are based on curves obtained on a General Electric Recording Spectrophotometer equipped with a Librascope Automatic Tristimulus Integrator, located in the Pioneering Research Laboratory, using freshly prepared magnesium oxide as the basic reflectance standard. Values of infrared reflectance were obtained from the spectral reflectance curve at one micron, as obtained on this instrument. Color difference measurements reported are based on the Adams formula (12). Certain of these samples were also studied with respect to diffuse spectral reflectance to 4.2 microns, using the White Corporation reflectance attachment to the Perkin-Elmer Infrared Spectrometer, Model 12-C, with a lithium fluoride prism. This instrument, based on the Sanderson (13) principle, is located in the Materials Laboratory, Wright Air Development Center.

7. Seam efficiency and yarn severance tests were performed by the Seams Laboratory of the Textile Materials Engineering Laboratory in accordance with test methods 5110 and 5400, respectively of Federal Specification CCC-T-191b. Standard conditions for testing textiles were observed throughout. Seams were made using the following conditions:

049 round point, ball eye needle
24/3 needle thread
60/3 looper thread
12-16 stitches per inch

8. Water repellency tests (spray rating, hydrostatic pressure and dynamic absorption) were conducted in accordance with Methods 5526, 5516, 5500 and 5518 of Federal Specification CCC-T-191b by the Functional Finishes Laboratory.

9. The following physical properties of the original fabrics were also determined by the Functional Finishes Laboratory in accordance with Methods 5100, 5132, 5122, 5030, 5041, 5450 and 5202 of Federal Specification CCC-T-191b.

Breaking strength - pounds - grab method
Elongation at break - percent
Tear strength - pounds, Elmendorf
Bursting strength - pounds
Thickness - inches, 0.625 pounds per square inch
Weight - ounces per square yard
Air Permeability - cubic feet of air per minute per square foot
Flexibility - at ambient temperature
at minus 20°F
after aging 6 hours at 200°F
after aging 6 hours at 200°F and one cotton mobile laundering

10. In addition, tests were conducted for resistance to anti-vesicant impregnation using the procedure outlined in Laboratory Directions No. 112 published by the Chemical Corps Technical Command, Protective Division. In this test the samples are impregnated with Impregnite XXCC3 on a two roll padder to provide ten percent by weight of the compound on the fabric in a manner previously described (14). The fabric is then aged for forty-six hours at 175°F (80°C), considered equivalent to box and bale storage for six months.

11. The samples tested are identified in the tables of the Appendix by the following code:

CODE DESIGNATION	SAMPLE DESCRIPTION
GO	General Ground Shade for Resin-Pigment Formulation
GR	General Ground Shade Treated with Resinous Water Repellent
AO	Resin Bonded Pigmented Fabric using Ground Shade GO Produced by Manufacturer "A"
AR	Fabric AO Treated with Resinous Water Repellent
AC	Fabric AO Treated with Cationic Water Repellent
BO	Resin Bonded Pigmented Fabric using Ground Shade GO Produced by Manufacturer "B"
BR	Fabric BO Treated with Resinous Water Repellent
BC	Fabric BO Treated with Cationic Water Repellent
CC	Resin Bonded Pigmented Fabric using Ground Shade GO and Treated with Cationic Water Repellent Produced by Manufacturer "C"
DO	Resin Bonded Pigmented Fabric using Ground Shade GO Produced by Manufacturer "D"
DC	Fabric DO Treated with Cationic Water Repellent

CODE DESIGNATION (cont'd)	SAMPLE DESCRIPTION
ST	Present Vat Dyed Standard for Olive Green 107 treated with Cationic Water Repellent
CV	Fabric Dyed with Newly Developed Vat Formulation Treated with Resinous Water Repellent
S	Fabric Dyed with Selected Sulfur Dye Formulation Treated with Resinous Water Repellent

RESULTS OBTAINED:

1. For the sake of convenience the detailed experimental data are tabulated in the Appendix to this report. These tables summarize the following:

Table I: Physical Properties of Original Test Fabrics for Comparison of Resin Bonded Pigment, Sulfur, and New Vat Dye Formulations for Control of Infrared Reflectance.

Table II: Sewability Characteristics of Original Test Fabrics for Comparison of Resin Bonded Pigment, Sulfur, and New Vat Dye Formulations for Control of Infrared Reflectance.

Table III: Water Repellency Characteristics of Test Fabrics for Comparison of Resin Bonded Pigment, Sulfur, and New Vat Dye Formulations for Control of Infrared Reflectance.

Table IV: Color Fastness Characteristics of Test Fabrics for Comparison of Resin Bonded Pigment, Sulfur, and New Vat Dye Formulations for Control of Infrared Reflectance.

Table V: Infrared Reflectance Values Observed in Fastness Tests of Test Fabrics for Comparison of Resin Bonded Pigment, Sulfur, and New Vat Dye Formulations for Control of Infrared Reflectance.

Table VI: and VI-a Resistance to Anti-vesicant Impregnation of Test Fabrics for Comparison of Resin Bonded Pigment, Sulfur, and New Vat Dye Formulations for Control of Infrared Reflectance.

Spectral reflectance curves are shown in the Appendix for all of the fabrics subjected to color fastness tests and representative samples of those treated with anti-vesicant impregnation. These curves cover the range from 400 to 1000 millimicrons, as obtained on the General Electric Recording Spectrophotometer. Also, diffuse spectral reflectance curves from 1.0 to 4.2 microns, as obtained on the White attachment to the Perkin-Elmer Infrared Spectrometer, are shown for four samples: the

present vat standard for Olive Green 107, the resin bonded pigment formulation, the sulfur dyed fabric, and the newly developed vat formulation. Code AR was selected from among the resin bonded pigmented fabrics because it came closest to matching the visual shade for Olive Green 107 and the recommended infrared reflectance value.

2. From an examination of the physical data of Table I it is evident that each sample is inferior in some characteristics and superior in others to the standard and to each other. In order better to evaluate the physical data, the values obtained on the two resin bonded pigmented fabrics treated with resinous water repellent were averaged. (Codes AR and BR). The values thus obtained were compared with the average values obtained from the four resin bonded pigmented fabrics treated with the cationic water repellent (Codes AC, BC, CC, DC), the standard, the special Calco vat, and the sulfur dyed fabrics. To place the data on a common basis, each factor was compared to the standard, which was arbitrarily assigned a rating of 100. Ratings with regard to the first four variables (breaking strength, elongation, tear strength, and bursting strength) are direct ratios of sample to standard. The last three variables (weight, air permeability, and flexibility) are evaluated as inverse ratios, because quality with respect to these parameters is an inverse function of the quantities measured. It is evident from this treatment of the data that, as far as physical properties are concerned, all of the colorant methods considered are at least as good as the standard from an over-all view, if equal importance can be assigned to each factor. The table below summarizes this analysis.

TABLE A

Comparison of Physical Properties of Resin Bonded Pigmented, Sulfur, and New Vat Dyed Fabrics with Standard

	AR, BR	AC, BC CC, DC	CV	S
Breaking Strength	121	119	96	104
Elongation	72	85	96	108
Tear Strength	97	102	129	110
Bursting Strength	129	128	122	113
Weight	98	97	107	97
Air Permeability	112	132	102	116
Flexibility	83	94	102	112
Average of all seven variables	102	108	108	109

3. From Table II it is evident that, with respect to seam efficiency and yarn severance, the Calco special vat and sulfur dyed fabrics are at least as good as the standard. A significant point observed in these data is the remarkable improvement in sewability of the resin bonded pigmented fabrics, after water repellent treatment, to the point where they may be considered almost as good as the standard. The improvement of these fabrics may be attributed in large part to the improved flexibility imparted by either type of water repellent.

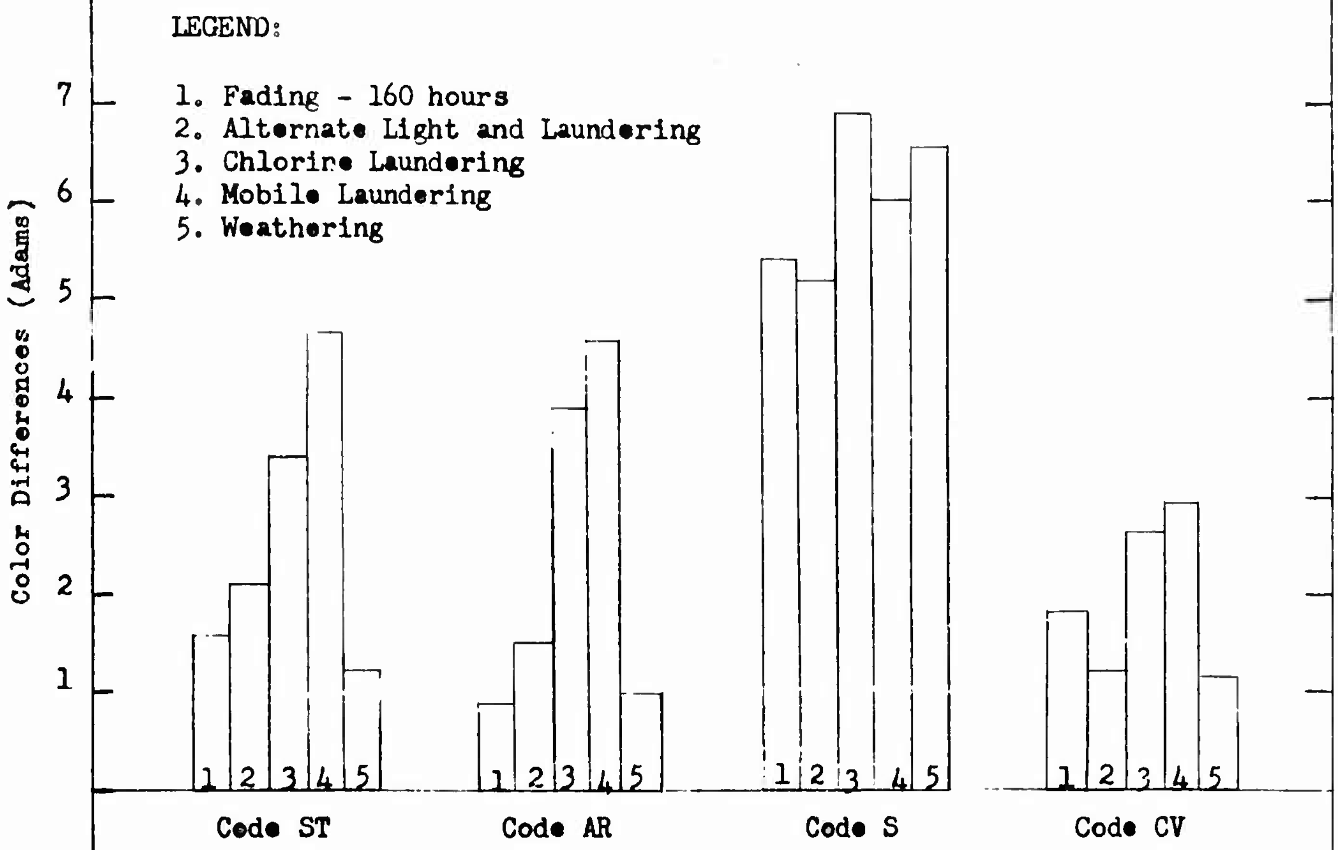
4. The water repellency data of Table III show nothing to alter previous observations to the effect that the water repellents used in this study give adequate results when properly applied, regardless of whether they are applied over vat dyed or resin bonded pigment bases.

5. Because the mass of data in Table IV requires considerable study in order to assess its full significance, Figure A is presented to summarize the observations with respect to color fastness. In this case the Calco special vat, sulfur dyed and resin bonded pigmented (Code AR) fabrics are compared to the standard with regard to the units (Adams) of color change calculated for each of the various tests. Fabric AR was selected because it was the best of the resin-pigmented fabrics produced with respect to visual shade, infrared reflectance, color fastness and ease with which the formulation was applied at Cramerton. The heights of the bars are directly proportional to the color changes observed. By integrating the area defined by the bars, an over-all evaluation of the color fastness may be assigned. Rating the samples on this basis places the formulations in the following rank order: Calco special vat (96), resin bonded pigment (119), standard (130), and sulfur (301) in order of decreasing fastness. Some of the other resin bonded pigmented fabrics are not as good as Code AR or AC. This is particularly true of Code CC and DC. The reasons for this relate to manufacturing difficulties discussed previously and will be considered in the Discussion.
(Figure A follows on succeeding page).

6. Table V presents the data on the infrared reflectance of all the test fabrics in the original state and also after the color fastness tests. The present standard has an infrared reflectance which is considered too high to provide adequate concealment in a cold-wet climate. Both the recently developed Calco vat dye formulation and the resin bonded pigment system achieve reflectance values which meet the recommendations of the Corps of Engineers. The specific sulfur dyed fabric has a reflectance in the region of sniperscope sensitivity which is much too low. It is unusual to find sulfur dyed fabrics, of a shade as deep as Olive Green 107, having infrared (sniperscope) reflectance very much higher than ten or twelve percent. It is possible, however, to alter the formulation by using selected sulfur dyes to meet the recommended conditions.

FIGURE A

COLOR CHANGES OBSERVED IN FASTNESS TESTS FOR STANDARD OLIVE GREEN 107, RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYED FABRICS



The data of Table V show what changes may be expected in infrared reflectance when fabrics are subjected to field conditions. Examination of this table shows that both the Calco special vat dyes and properly applied resin bonded pigment formulations will provide infrared reflectance values within the allowable limits recommended by the Corps of Engineers during the life of the garment. The poorest sample of the group with respect to fastness in infrared reflectance is the sulfur dyed fabric. If adjustments were made to provide proper infrared reflectance on the original fabric, the reflectance of the fabric in field use would increase rapidly, to the point where it would soon be outside the recommended limits.

7. Data of Table VI, illustrating the effect of Impregnite XXCC-3 on the breaking strength of the test fabrics, show conclusively that none of the formulations can be expected to withstand well the extreme degradative conditions which exist in the test. This test requires that for a fabric to be considered satisfactory, it must retain fifty percent of its strength and fifty percent of the anti-vesicant after impregnation with ten percent Impregnite XXCC and subsequent aging. The water repellent treatments on some of the resin bonded pigmented fabrics prevented absorption of the requisite ten percent anti-vesicant. Samples of fabric considered in this report, submitted to the Army Chemical Center, were subjected to the same analysis by the Chemical and Radiological Laboratories. In these tests, the samples were aged for seventeen or twenty-three hours, a departure from instructions cited above to allow a better comparison of fabrics. These data [16], summarized in Table VI-a, are in substantial agreement with results obtained in these laboratories. Recognizing the departure from the above conditions, the only observation which can be made with assurance is that the resin bonded pigmented fabrics, when properly treated with water repellents are superior to the standard, the recently developed vat formulation and the sulfur dyed fabrics. Previous studies [11] have shown a superiority of the resinous type over cationic type water repellents with respect to the protection afforded fabrics from the ravages of Impregnite.

In this connection the most obvious difference between the various test fabrics occurs in the effect of the anti-vesicant on the color of the fabric. Spectral reflectance curves, which are presented in the Appendix, show that the resin bonded pigmented fabrics are virtually unaffected with regard to color and infrared reflectance, as compared with the other fabrics. The Calco special vat dyed sample becomes a deep rose or brick red color after aging; the standard Olive Green 107 and the sulfur dyed fabrics are bleached to a pale, dirty yellow.

8. Spectral reflectance curves to 4.2 microns, as obtained on the White attachment to the Perkin-Elmer Infrared Spectrometer, show that only the resin bonded pigmented fabrics can be depended upon to provide

low reflectance throughout this spectral region of future interest. The basic characteristics of these fabrics which stand out in these figures are a) the sharp rise in the reflectance curve of vat dyes beginning at about 700 millimicrons to a very high value in the two micron region, b) the comparatively constant reflectance value observed on the resin bonded pigmented fabric between 1.0 and 2.3 microns, and c) the intermediate values observed for the sulfur dyed fabric. It was pointed out earlier that the sulfur dyed fabric had too low a reflectance in the one micron region. The reflectance at 1.0 micron was 9 percent and at two microns about twenty-five percent (the exact value depends on the amount of moisture in the fabric). If adjustments in the formulation were made to provide a reflectance of twenty percent at one micron, the reflectance at two microns would be approximately forty percent. Furthermore, the poor fastness properties of this fabric would result in even higher values after relatively limited field use. The Calco special vat dyed fabric shows little improvement over the present standard beyond one micron. Consideration of the near infrared spectral region beyond one micron is discussed more fully in another report by one of the authors (15).

ANALYTICAL DISCUSSION OF THE RESULTS OBTAINED:

In discussing the methods presently available for obtaining optimum reflectance in the infrared region of the spectrum, a brief analysis of each colorant system would seem to be in order.

1. The present vat dyed standard for Olive Green 107, considered as the reference point for all evaluations except infrared reflectance, stands out as a vast improvement over previous uniform material. For any of the other fabrics to be considered adequate, they must compare favorably with this standard with respect to color fastness and physical properties and still meet the infrared requirements.

2. The Calco-developed special vat formulation rates favorably with the standard with regard to the physical properties reported in Tables I and II; in some instances it actually surpasses the standard.

Dynamic absorption data, presented in Table III, show that the values for this fabric (and also for some of the resin bonded pigmented fabrics) are high, although with respect to spray rating and hydrostatic pressure measurements, its performance is excellent. Such data may indicate that removal of surface active agents used in the dyeing operation was incomplete. The new vat dyes, as represented specifically by the formulation chosen for this study, will show little color deterioration in field use and comprise, in fact, the only colorant system which may be considered equal to or better than the standard in every fastness test. Only with respect to light fastness is this formulation surpassed by the resin bonded pigmented system. The new dyes have satisfactory

spectral properties initially, yet, unlike the sulfur dyes which deteriorate readily, the recently developed vat formulation retains these desirable properties over a large number of cycles of all degradative tests (except resistance to Impregnite), both in visual shade and infrared reflectance.

The curves in the Appendix, showing the diffuse spectral reflectance in the range to 4.2 microns, demonstrate the very sharp rise in reflectance for these fabrics at one micron. These new dyes are adequate, therefore, to produce fabrics having satisfactory camouflage properties only against the US Sniperscope, Model M-2, or similar instruments. If image forming devices capable of detecting radiation beyond 1.2 microns were employed, these dyes would offer no advantage over the present standard.

As is evident from the data of Table VI and reflectance curves in the Appendix, the disintegration of this fabric in the presence of CWS Impregnite is virtually complete. It is interesting to note, referring to Figure 22, the shift of the absorption maximum at about 700 mμ to almost 800 mμ during this treatment, thereby extending further into the infrared the region of controlled reflectance. The chemical processes involved in this treatment and the effect it has on the dyestuffs used in this vat formulation may provide a clue as to how chemical structure may be modified to produce dyestuffs having absorption maxima at longer wavelengths.

3. It was pointed out previously that the apparently good infrared properties of the sulfur dyed fabric are not real, because the reflectance in the range of sniperscope sensitivity is too low. If adjustments were made in the formulation to achieve proper reflectance in the one micron range, then the reflectance in extended regions of the infrared would probably be too high. Furthermore, the deterioration of color in all phases of the color fastness tests precludes further consideration of this type of dyeing for military fabrics. Vat dyes are far superior in the visual range, while both the recently developed special vat and the resin bonded inorganic pigment system are superior in the infrared. In addition, the sulfur dyed fabric demonstrated no resistance to Impregnite XXCC3 treatment.

4. In considering the resin bonded inorganic pigment system certain factors, which are unique to this colorant technique, must be discussed in detail. The departure from usual dyeing procedures emphasizesfactors previously considered of comparatively minor concern, at least as far as evaluating colorant systems. The physical condition of the resin bonded pigmented fabrics before treatment with water repellents or laundering is considered rather poor. The fabrics in the original condition are quite stiff, resulting in poor tear strength, hand, and sewability. Upon treatment with either water repellent, however, these

deficiencies were largely overcome. Further improvement results after laundering.

The resin bonded pigmented fabrics considered in this report differ from the special vat dyed and sulfur dyed fabrics in that they are products of four different manufacturers and were produced with formulations which differ somewhat from each other. The chemical nature of the pigments is similar but the physical state of these pigments, the resins and emulsifiers used in the padding liquor differ considerably. Differences in formulation, to a greater degree than any other factor, account for the variations observed in the production runs and final fabric. The comparative lack of compatibility of components in the padding liquor was the cause of the excessive flushing of carbon black experienced in the run by manufacturer "C". To illustrate the effect of this comparatively poor formulation, compare fabric CC with samples AC, BC, and DC through the various phases of the evaluation. Since these fabrics were produced on the same lot of fabric, treated with the same water repellent, and produced by the same personnel, the deviations observed, being more than statistical, cannot be attributed to these factors.

The result of carbon black flushing to the surface was to give fabrics which were too dark and dull visually and somewhat lower in infrared reflectance than the others. Because of the poorer emulsion this fabric showed poor fastness in the laundering tests. It had the effect, however, of producing a fabric with outstanding fastness to light, because the carbon black on the surface of the fabric is virtually inert under such conditions and covered the more light sensitive colorants. Furthermore, fabric CC rates much lower than the others in the strength measurements (breaking, tear, and bursting), although ostensibly treated in the same manner.

It was conceded by manufacturer "C" that the fabric processed with his formulation was unsatisfactory, and the run was terminated after only one-fifth of the planned production had been completed. Since the completion of the production run at the Cramerton plant, this pigment manufacturer has devoted considerable laboratory research to improve his product. It is now believed that this has been effected, although not proven in production.

Discounting fabric CC, inspection of the experimental data reveals that the resin bonded pigment system, when properly treated with water repellents, may be considered excellent. It rates slightly above the standard in physical properties and color fastness and only slightly below the standard in sewability. In color fastness it is somewhat surpassed by the recently developed vat dye formulation of Calco.

The differences noted in the data of Tables I, II, III and IV are small and any deficiency of the resin bonded pigmented fabrics in these factors are more than compensated when the advantages unique to this colorant system are considered. The three successful runs produced fabric within the limits for infrared reflectance, recommended by the Corps of Engineers as 20% ± 5%. The original fabrics have values of reflectance at one micron of approximately eighteen percent which rise during the expected life of a garment to about twenty-two percent, entirely within the allowable range for optimum camouflage. The spectral reflectance of these fabrics remains almost constant from one micron out to about 2.5 microns, the expected practical limit for active, image forming viewing devices (15). Furthermore, the principles involved in this system allow for wide flexibility in practice. By changing the ground shade and chromatic pigments, any of the heavier military shades can be matched visually, and still provide control of infrared reflectance. In fact, the technique has been modified for wool and wool-nylon fabrics (3) resulting in a reflectance of about twenty percent throughout the near infrared to 2.3 microns (15) on a sample which matched the visual shade Olive Green 108. It is believed that the spectral reflectance of the resin bonded pigmented cotton fabrics and incidentally, the acid-colloid treated wool fabrics, approach the anticipated requirements for good camouflage in the near infrared to 2.5 microns. An important advantage of this colorant system is that indicated corrective measures can be taken with relative ease.

Ability of the resin bonded pigmented fabrics to resist to a degree the extreme degradative effects of Impregnite XXCC-3 is an important difference observed among the fabrics. Although considerable physical degradation of the fabrics and anti-vesicant occurs, the effect of Impregnite XXCC-3 on the color of these fabrics is negligible compared with the total break-down observed for vat and sulfur dyed fabrics.

5. The double dyeing procedure which is necessary for production of resin bonded pigmented fabrics adds to the cost. Differences in the cost of producing end item ensembles using resin bonded pigments at an estimated increased cost of $0.09 per yard or the Calco special vat dyes at an estimated increased cost of $0.05 per yard are tabulated below.

The following figures, given for the resin bonded pigment system, are, necessarily, based on fitting the operation into the existing facilities of the particular plant chosen for this study. In the production run at the Cramerton Division of Burlington Mills, the fabric was first vat dyed and dried. It was then pigment padded and fed through a dryer, tenter framed, and oven cured in one continuous operation. This was followed by the water repellency treatment which repeated these operations again. In this manner the complete production extended about three times as long as

it might have under more efficient operation. Rehandling of fabric and the fact that the equipment could handle only one step at a time contribute a major portion of the cost differential observed. If application of resin bonded pigments were to become a routine production method, considerable savings in the following estimates could be realized by synchronization of the steps involved.

Estimated Increased Cost

Item	Cost	Increased Cost Percent
Trousers, shell, field, M-1951		
a. As procured at present	$6.98	--
b. Procured with resin bonded pigment treated fabric	7.24	3.7
c. Procured with new QM vat dyed fabric	7.12	2.0
Jacket, shell, field, M-1951		
a. As procured at present	13.50	--
b. As procured with resin bonded pigmented fabric	13.98	3.6
c. As procured with new QM vat dyed fabric	13.77	2.0

6. As noted in previous studies (11) the resistance to Impregnite XXCC-3 is a function not only of the basic colorant formulation, but to a marked degree of the type of water repellent used in finishing. The resinous type of repellent gives a measure of protection, while cationic types appear to hasten the degradative processes.

7. From the standpoint of commercial production, both the resin bonded pigment system and the new vat dye formulation are practical. The colorants and resins for the former technique are readily available. The dyestuffs for the new vat formulation could be mass produced with existing equipment. The minor difficulties encountered at the Cramerton Mills were of an engineering nature and could be overcome quite readily by mill personnel. The knowledge obtained during the production run will prevent a recurrence of the experience of manufacturer "C".

CONCLUSIONS REACHED:

The results of this investigation lead to certain unequivocal conclusions:

1. No fabric tested in connection with this report has completely adequate resistance to the anti-vesicant, Impregnite XXCC-3. The nature of this material is such that it is an exceedingly active oxidizing agent which is capable of severely attacking cellulose or protein fibers.

If subjection of fabric to such treatment can be avoided, then the matter of developing colorants for textiles to provide camouflage against the present type sniperscope can be considered concluded. Two colorant systems, the resin bonded inorganic pigment and a recently developed vat dye formulation present two practical solutions to the problem.

2. The poor resistance to anti-vesicant impregnation shown particularly by the vat and sulfur dyes, and to a degree by the resin bonded pigmented fabrics, may be correctible by either chemical modifications of molecular structure of colorants or by the development of resins which afford better protection to the fabric.

3. From a long range viewpoint, the resin bonded pigment system, even though it may be somewhat more costly and with certain minor deficiencies with respect to physical properties of the fabrics, proves the better answer to the infrared camouflage problem. When one considers that a colorant system has been developed which has good fastness properties, is adaptable to many different shades on different fibers, better resistance to anti-vesicant impregnation and provides control of reflectance throughout the useful near infrared spectrum, the minor deficiencies observed are entirely over-shadowed.

4. Because the research contract with the Calco Chemical Company was successful in developing vat dyes which extended the range of controlled reflectance and observations made in this report on the effect of chemical treatments on the reflectance spectrum of these dyes, the search for colorfast dyes, which can impart lower reflectance beyond one micron, appears hopeful.

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APPENDIX

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PART A: TABLES OF EXPERIMENTAL DATA.

TABLE I

PHYSICAL PROPERTIES OF ORIGINAL TEST FABRICS FOR COMPARISON OF RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYE FORMULATIONS FOR CONTROL OF INFRARED REFLECTANCE

Sample Code	Breaking Strength (Pounds) Warp	Breaking Strength (Pounds) Filling	Elongation at break (Percent) Warp	Elongation at break (Percent) Filling	Tear Strength (Pounds) Warp	Tear Strength (Pounds) Filling	Bursting Strength (Pounds)
GO	203	200	13.2	26.5	6.2	8.4	165
GR	171	165	18.9	18.9	8.5	12.1	218
AO	174	182	13.7	20.4	5.4	6.7	219
AR	165	166	11.8	24.6	6.2	9.7	258
AC	156	165	14.7	21.8	8.4	12.9	256
BO	168	191	14.2	21.8	5.0	7.3	237
BR	183	184	12.3	19.4	6.6	10.1	192
BC	192	196	15.6	18.9	8.2	13.5	258
CC	144	136	16.1	24.1	4.8	5.4	183
DO	189	208	15.2	26.0	5.3	6.3	207
DC	176	183	18.9	25.6	6.2	9.4	195
ST	166	128	17.5	29.4	8.0	8.7	174
CV	139	139	18.9	24.6	8.6	13.1	212
S	151	150	18.9	31.3	8.2	10.3	197

TABLE I (Cont'd)

PHYSICAL PROPERTIES OF ORIGINAL TEST FABRICS FOR COMPARISON OF RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYE FORMULATIONS FOR CONTROL OF INFRARED REFLECTANCE

Sample Code	Thickness (Inches) (0.625 psi.)	Weight (Ounces/sq.yd.)	Air Permeability (Cu.ft./min./sq.ft.)	Flexibility At Room Temp.	Flexibility At -20°F	Flexibility (After aging at 220°F for 6 hrs) Before Laundering	Flexibility (After aging at 220°F for 6 hrs) After one Mobile Laundering
GO	0.018	8.85	5.59	3.2	3.2	3.2	2.8
GR	0.020	9.27	5.52	2.7	2.5	3.8	2.4
AO	0.019	8.99	4.58	5.3	5.1	>6	2.9
AR	0.019	9.52	4.80	3.9	3.9	4.4	3.0
AC	0.020	9.38	5.82	3.2	3.6	3.8	3.0
BO	0.019	9.29	3.32	4.1	3.4	5.0	2.9
BR	0.020	9.33	5.59	2.9	2.7	3.9	2.5
BC	0.021	9.63	4.70	2.3	2.5	2.9	2.9
CC	0.021	9.58	3.19	3.1	2.4	3.4	2.9
DO	0.019	8.99	5.12	2.5	3.5	3.0	2.5
DC	0.019	9.47	4.58	2.8	3.0	3.5	2.6
ST	0.020	9.26	6.04	2.9	3.1	3.4	2.0
CV	0.020	8.64	5.92	2.8	2.6	3.7	2.2
S	0.022	9.51	5.20	2.4	2.7	3.2	2.4

TABLE II

SEWABILITY CHARACTERISTICS OF ORIGINAL TEST FABRICS FOR COMPARISON OF RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYE FORMULATIONS FOR CONTROL OF INFRARED REFLECTANCE

Sample Code	Fabric Strength (Pounds)	Seam Strength (Pounds)	Seam Efficiency* (Percent)	Yarn Severance** (Number) Warp	Filling
GO	196	135	69	1	20
GR	157	146	93	0	0
AO	192	135	72	9	23
AR	181	161	89	1	3
AC	182	172	95	1	1
BO	222	116	52	22	42
BR	171	145	85	3	5
BC	191	174	91	0	1
CC	176	164	93	0	0
DO	189	99	53	10	40
DC	181	150	83	2	3
ST	131	126	96	0	0
CV	140	139	100	0	0
S	145	146	100	0	0

* Average of 5 tests
** Average of 3 tests

TABLE III

WATER REPELLENCY CHARACTERISTICS OF TEST FABRICS FOR COMPARISON OF RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYE FORMULATIONS FOR CONTROL OF INFRARED REFLECTANCE

Sample Code	Spray Rating % Initial	Spray Rating % After Laundering	Hydrostatic Pressure Cm. Initial	Hydrostatic Pressure Cm. After Laundering	Dynamic Absorption % Initial	Dynamic Absorption % After Laundering
GO	50	--	16.3	--	--	--
GR	100	90	42.6	22.9	15.6	32.0
AO	70	--	28.0	--	--	--
AR	100	80	39.7	29.8	15.0	24.6
AC	100	80	38.0	21.5	18.4	30.6
BO	50	--	17.8	--	--	--
BR	100	70	40.9	25.4	37.7	35.5
BC	70	70	36.9	25.0	25.7	36.9
CC	70	100	39.3	24.0	35.0	27.9
DO	0	--	16.3	--	--	--
DC	90	70	42.4	26.5	31.6	39.3
ST	100	80	39.5	25.8	14.4	29.2
CV	100	80	32.1	21.5	33.7	42.0
S	90	70	30.0	22.3	44.2	45.1

TABLE IV

COLOR CHANGES OBSERVED IN FASTNESS TESTS ON TEST FABRICS FOR COMPARISON OF RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYE FORMULATIONS FOR CONTROL OF INFRARED REFLECTANCE

Sample Code	Light Fastness 160 hrs	Alt. Light & Laundry 5 cycles	Chlorine Laundry 20 cycles	Mobile Laundry 30 cycles	Weathering 100 hours
GO	0.9*	1.9	4.0	4.9	2.0
GR	0.9	2.0	2.9	4.6	1.6
AO	0.9	2.6	4.8	6.5	1.1
AR	0.9	1.5	3.9	4.6	1.0
AC	0.7	1.1	3.4	4.9	0.9
BO	0.5	3.1	4.5	6.6	1.0
BR	0.4	1.1	4.8	6.3	1.0
BC	1.1	1.6	3.9	6.1	1.1
CC	0.1	1.8	6.6	8.6	0.9
DO	1.6	2.6	4.5	6.7	1.3
DC	1.0	2.1	4.2	5.6	1.1
ST	1.6	2.1	3.4	4.7	1.2
CV	1.8	1.2	2.6	2.9	1.1
S	5.4	5.2	6.9	6.0	6.6

*Note: The units of color difference are those defined by reference 12 and one such unit is considered a difference in color no greater than would be acceptable as a commercial match.

TABLE V

INFRARED REFLECTANCE VALUES OBSERVED IN FASTNESS TESTS ON TEST FABRICS FOR COMPARISON OF RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYE FORMULATIONS FOR CONTROL OF INFRARED REFLECTANCE

Sample Code	Initial Value	Light Fastness 160 hrs	Alt.Light & Laundry 5 cycles	Chlorine Laundry 20 cycles	Mobile Laundry 30 cycles	Weathering 100 hours
GO	44.0	45.5	43.5	42.0	43.0	43.5
GR	44.0	46.5	45.5	48.0	45.5	42.5
AO	18.0	18.0	18.5	20.5	22.0	17.0
AR	18.0	18.0	19.0	21.5	21.5	17.5
AC	17.5	17.0	18.5	20.0	21.0	17.5
BO	19.0	19.0	22.0	21.5	24.5	18.0
BR	15.5	16.0	17.0	21.0	23.0	16.0
BC	17.0	16.0	17.5	20.5	22.5	17.0
CC	14.0	14.0	15.5	19.5	21.5	14.5
DO	15.5	17.5	18.5	20.0	22.5	15.5
DC	15.5	16.0	18.0	20.5	21.0	16.0
ST	32.0	32.5	32.5	32.0	34.0	33.0
CV	20.0	19.0	20.0	21.0	21.0	20.0
S	9.5	15.5	15.0	20.5	13.0	16.5

TABLE VI

RESISTANCE TO IMPREGNITE XXCC-3 OF ORIGINAL TEST FABRICS FOR
COMPARISON OF RESIN BONDED INORGANIC PIGMENT,
SULFUR, AND NEW VAT DYE FORMULATIONS FOR
CONTROL OF INFRARED REFLECTANCE

Sample Code	Tensile Strength: Original Warp	Original Filling	After Age Warp	After Age Filling	% Loss Warp	% Loss Filling	% Impregnite After Pad	% Impregnite After Age
GO	165	159	91	71	45	45	8.7	0
GR	130	104	44	43	66	59	6.3	0
AO	128	104	45	42	65	60	7.9	0
AR	150	131	54	54	64	59	8.2	0
AC	95	[illegible]5	56	47	41	45	4.8	0
BO	111	103	64	61	42	41	6.1	0
BR	14[illegible]	134	49	42	67	69	10.5	0
BC	117	117	75	60	36	48	4.2	0
CC	117	101	43	26	63	74	7.8	0
DO	117	114	31	18	74	84	6.8	0
DC	123	103	30	23	76	77	8.2	0
ST	130	106	0	0	100	100	12.5	0
CV	145	119	13	8	91	93	11.3	0
S	139	122	19	14	87	89	11.6	0

TABLE VI-A*

RESISTANCE TO IMPREGNITE XXCC-3 OF ORIGINAL TEST FABRICS FOR COMPARISON OF RESIN BONDED INORGANIC PIGMENT, SULFUR, AND NEW VAT DYE FORMULATIONS FOR CONTROL OF INFRARED REFLECTANCE

Sample Code	XXCC-3 Applied %	Hours of Aging	Loss of XXCC-3, %	Tensile Strength Loss, %	Color Change	Receptivity to Impregnite**	Compatible (Color Change Excepted)
GO	9.50	17	40	3	Greenish-yellow	Good	Yes
GR	7.00	17	96	31	Normal	Poor	No
AO	8.29	23	93	54	Normal	Poor	No
AR	6.77	17	82	25	Normal	Poor	No
AC	6.45	23	94	66	Normal	Poor	No
BO	9.50	23	93	64	Normal	Good	No
BR	7.20	23	91	45	Normal	Poor	No
BC	6.65	23	98	76	Normal	Poor	No
CC	7.68	23	96	46	Normal	Good	No
DO	8.76	23	83	40	Normal	Poor	No
DC	5.95	17	85	12	Normal	Good	No
ST	7.13	23	99	66	Greenish-yellow	Good	No
CV	6.55	23	91	22	Brown	Poor	No
S	9.96	17	91	53	Greenish-brown	Poor	No

* Data submitted Chemical and Radiological Laboratories, Army Chemical Center (16).

** Samples that have poor receptivity to Impregnite picked up the greater portion of the XXCC-3 on the surface of the fabric. Modification of the Impregnation formulation would be necessary for the satisfactory impregnation of these fabrics.

PART B: COLORANT FORMULATIONS OF TEST FABRICS

Present Vat Dyed Standard, Olive Green 107.

Vat Olive T
Vat Olive Green B -- Pr 293
Vat Khaki 2G -- Pr 122
Shaded with a small amount of Vat Yellow GC -- Pr 9

Sulfur Dyed Fabric (Approximately Olive Green 107).

Calcogene Olive GCF, conc.
Calcogene Olive Drab YCF
Calcogene Brown NLCF
Shaded with small amounts of
Calcogene Bordeaux GR, conc.
Calcogene Green YSCF, conc.

Vat Dyed Ground Shade.

Vat Olive T
Vat Olive Green B -- Pr 293
Vat Khaki 2G -- Pr 122

New Quartermaster Vat Dyed Fabric.

Research Product I-146
Research Product I-99
Shaded with Vat Brilliant Green BN

Resin Bonded Inorganic Pigmented Fabrics.

The formulations used were of the manufacturers' own choosing, and were, in general, their own products.

Manufacturer "A".

Carbon black dispersion
Chromic oxide dispersion
Binder- oil modified alkyd resin, butylated melamine and a little acrylonitrile-butadiene copolymer
Sodium alginate
Ammonia
Oleic acid

Manufacturer "B".

Carbon black dispersion
Yellow iron oxide dispersion
Green (Prussian blue, barium chromate) dispersion
Binder-butylated melamine and oil modified alkyd resin
Sodium alginate
Ammonia
Oleic acid

Manufacturer "C".

Carbon black dispersion
Chromic oxide dispersion
Binder-butylated melamine and oil modified alkyd resin
Ammonia
Sodium alginate
Oleic acid

Manufacturer "D".

Carbon black dispersion
Chromic oxide dispersion
Binder-alkyd resin, ethyl cellulose, and butylated melamine
Ammonia
Sodium alginate
Oleic acid

PART C: SPECTRAL REFLECTANCE CURVES OF TEST FABRICS SHOWING EFFECTS OF THE VARIOUS FASTNESS TESTS, FROM 400 MILLIMICRONS TO 1000 MILLIMICRONS.

Figures 1 and 1a* :	General Ground Shade, Code GO.
Figures 2 and 2a :	General Ground Shade, Code GR.
Figures 3 and 3a :	Resin Bonded Inorganic Pigmented Fabric, Code AO.
Figures 4 and 4a :	Resin Bonded Inorganic Pigmented Fabric, Code AR.
Figures 5 and 5a :	Resin Bonded Inorganic Pigmented Fabric, Code AC.
Figures 6 and 6a :	Resin Bonded Inorganic Pigmented Fabric, Code BO.
Figures 7 and 7a :	Resin Bonded Inorganic Pigmented Fabric, Code BR.
Figures 8 and 8a :	Resin Bonded Inorganic Pigmented Fabric, Code BC.
Figures 9 and 9a :	Resin Bonded Inorganic Pigmented Fabric, Code CC.
Figures 10 and 10a:	Resin Bonded Inorganic Pigmented Fabric, Code DO.
Figures 11 and 11a:	Resin Bonded Inorganic Pigmented Fabric, Code DC.
Figures 12 and 12a:	Present Vat Dyed Standard for Olive Green 107, Code ST.
Figures 13 and 13a:	New Quartermaster Developed Vat Dyed Fabric, Code CV.
Figures 14 and 14a:	Sulfur Dyed Fabric, Code S.

* Two figures are shown for each sample; the first contains the curves of the original, after 160 hours exposure in the Fadeometer, 30 cycles of mobile laundering, and 5 cycles of alternate laundering and exposure to light; the second figure, designated with the letter 'a', contains curves for exposure to weathering, chlorine laundering and the original fabric.

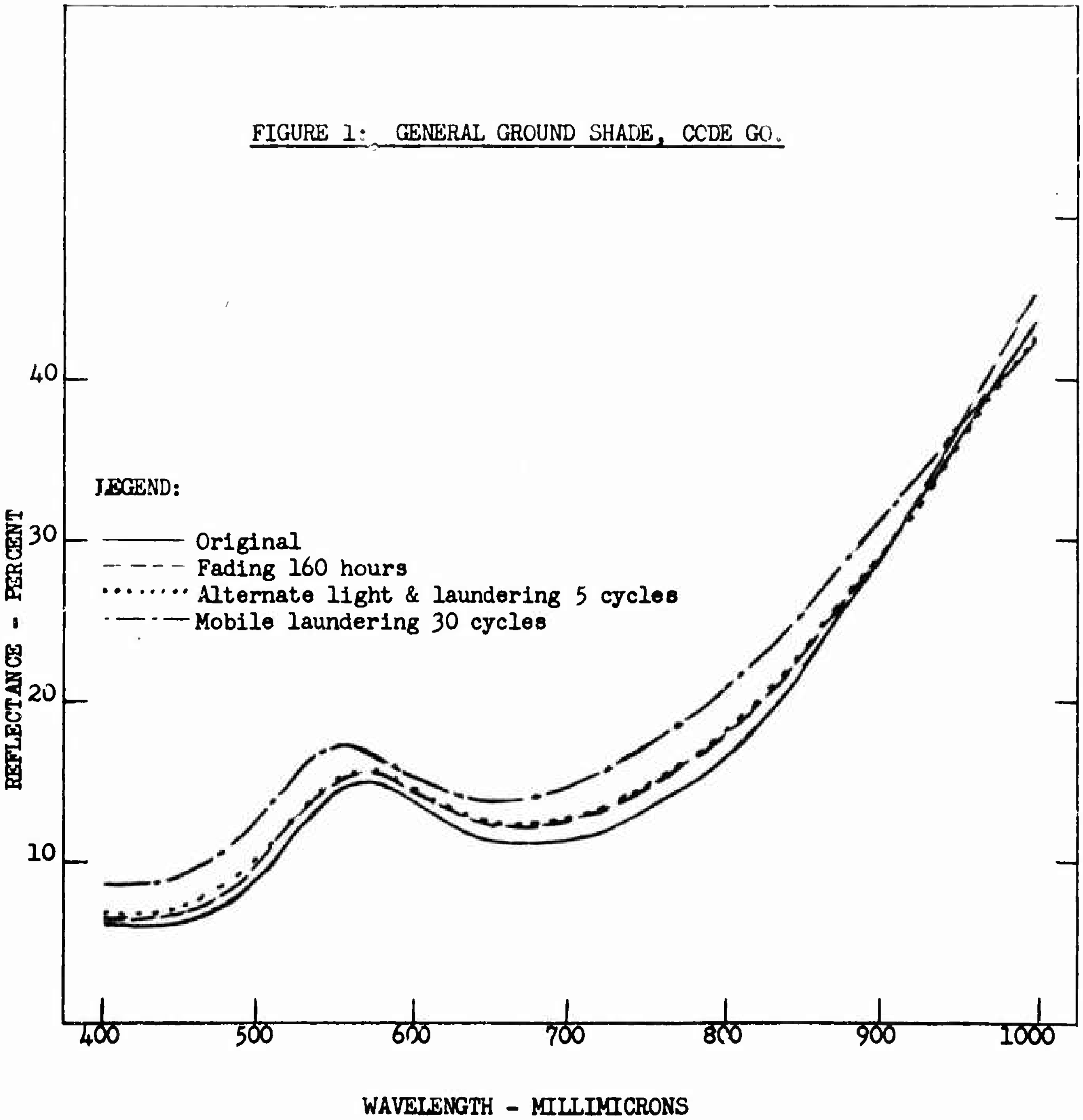


FIGURE 1: GENERAL GROUND SHADE, CODE GO.
LEGEND:
Original
Fading 160 hours
Alternate light & laundering 5 cycles
Mobile laundering 30 cycles
REFLECTANCE - PERCENT
10
20
30
40
400
500
600
700
800
900
1000
WAVELENGTH - MILLIMICRONS

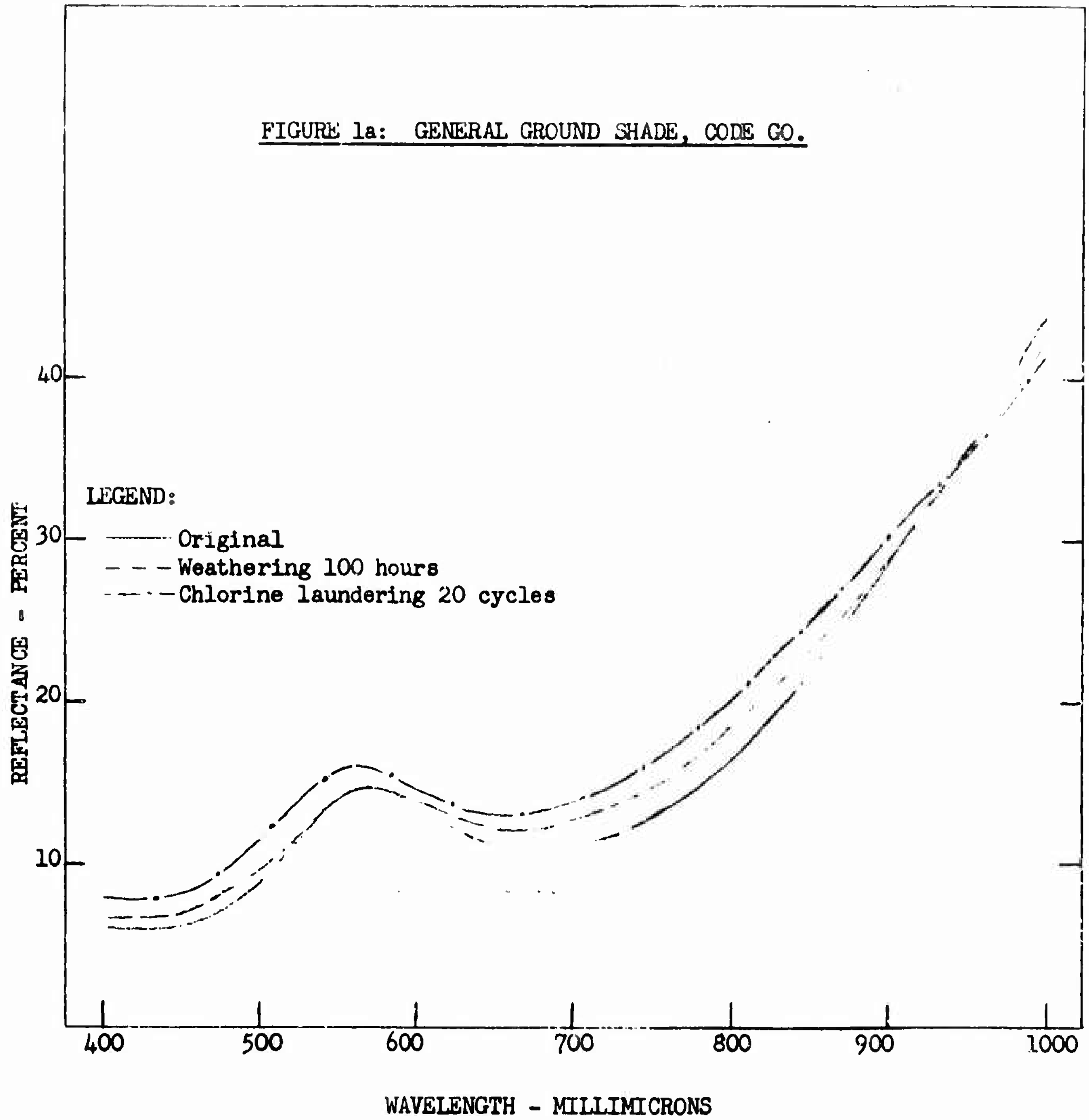


FIGURE 1a: GENERAL GROUND SHADE, CODE GO.
40
30
20
10
LEGEND:
Original
Weathering 100 hours
Chlorine laundering 20 cycles
REFLECTANCE - PERCENT
400
500
600
700
800
900
1000
WAVELENGTH - MILLIMICRONS

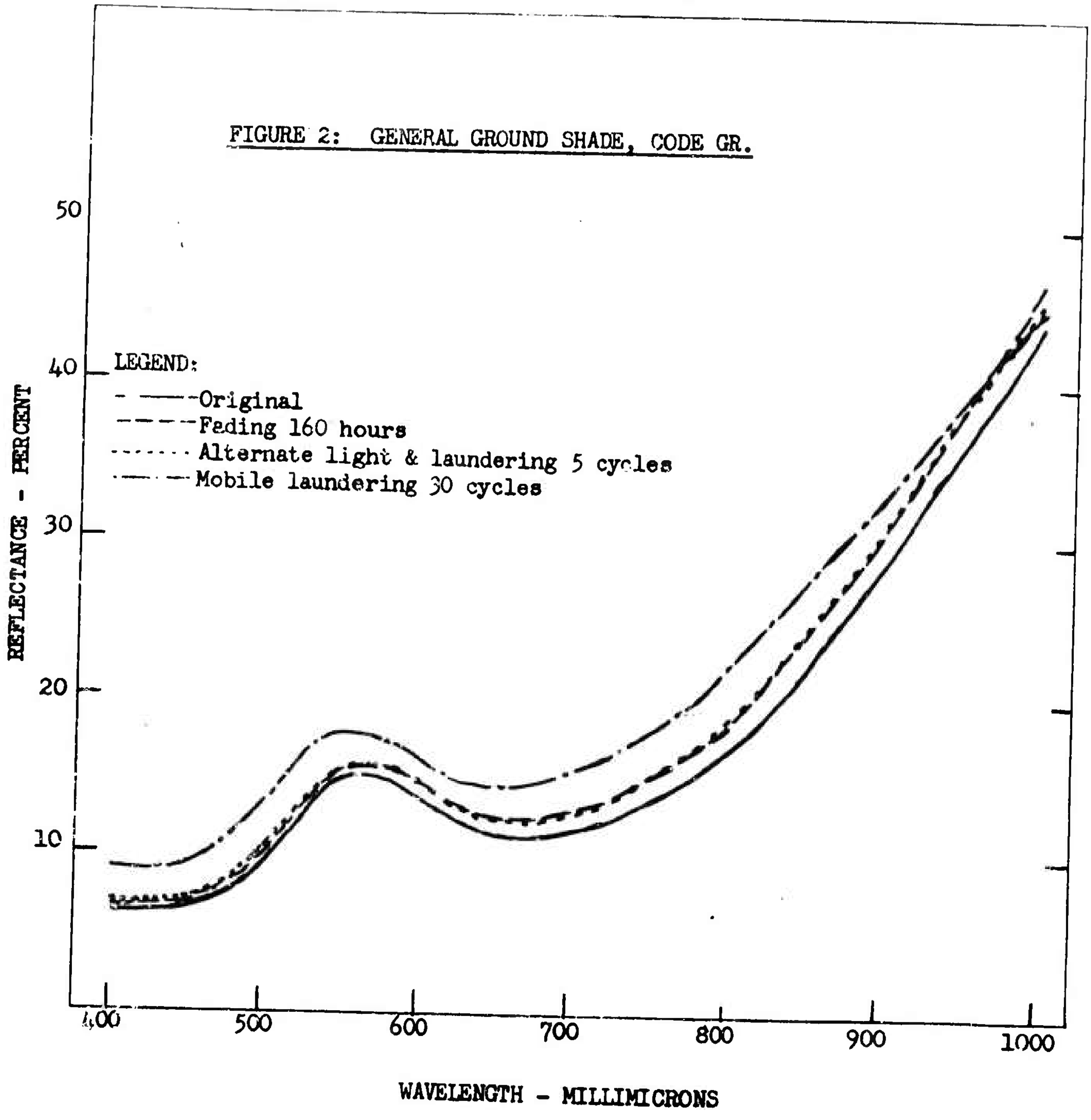


FIGURE 2: GENERAL GROUND SHADE, CODE GR.
LEGEND:
Original
Fading 160 hours
Alternate light & laundering 5 cycles
Mobile laundering 30 cycles
REFLECTANCE - PERCENT
10
20
30
40
50
400
500
600
700
800
900
1000
WAVELENGTH - MILLIMICRONS

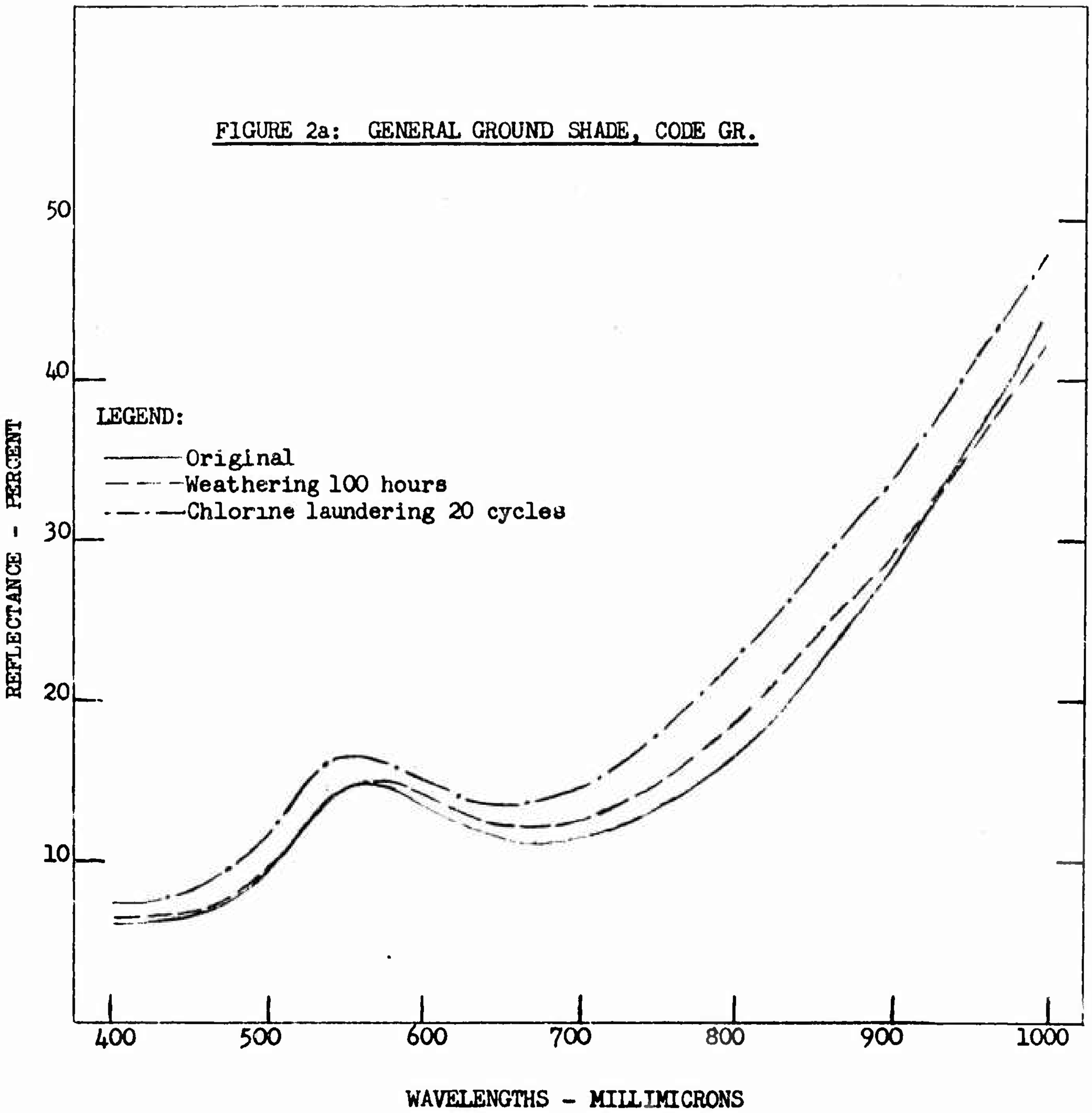


FIGURE 2a: GENERAL GROUND SHADE, CODE GR.
50
40
30
20
10
REFLECTANCE - PERCENT
LEGEND:
Original
Weathering 100 hours
Chlorine laundering 20 cycles
400
500
600
700
800
900
1000
WAVELENGTHS - MILLIMICRONS

FIGURE 3: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AO.

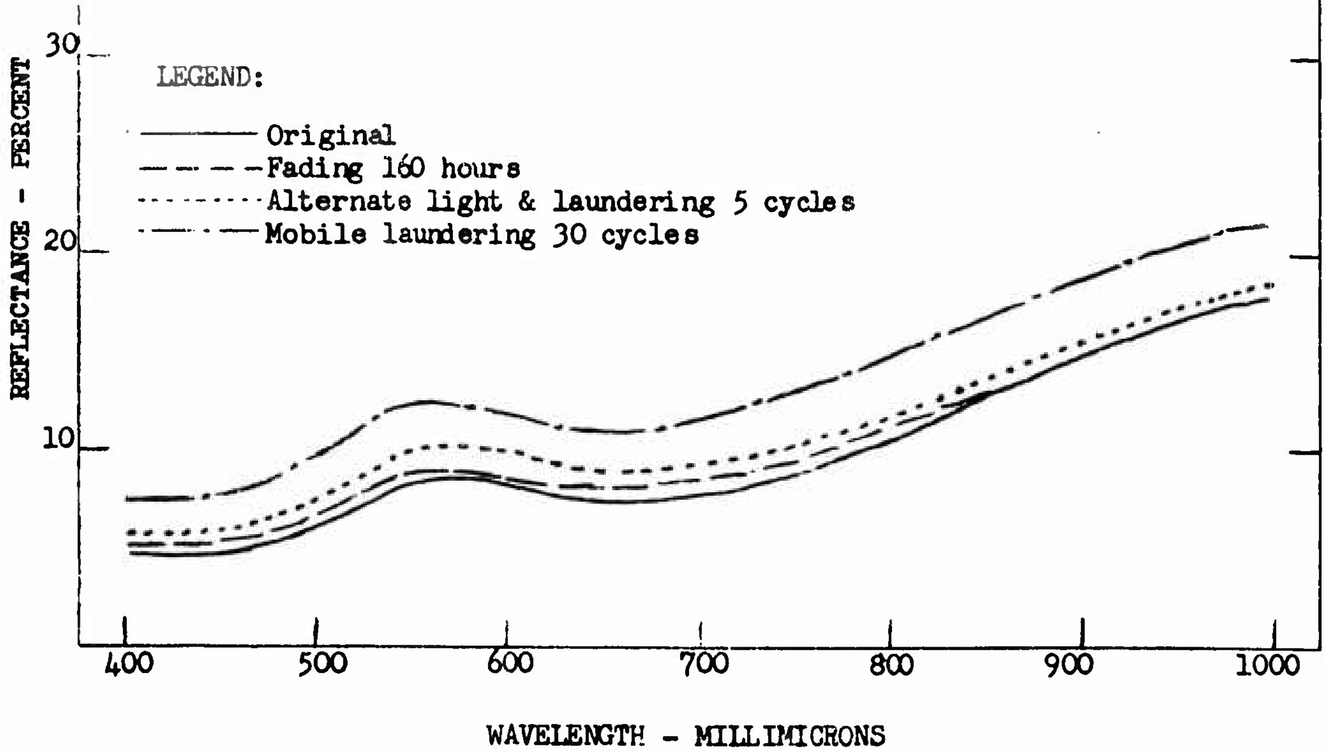


FIGURE 3a. RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AO.

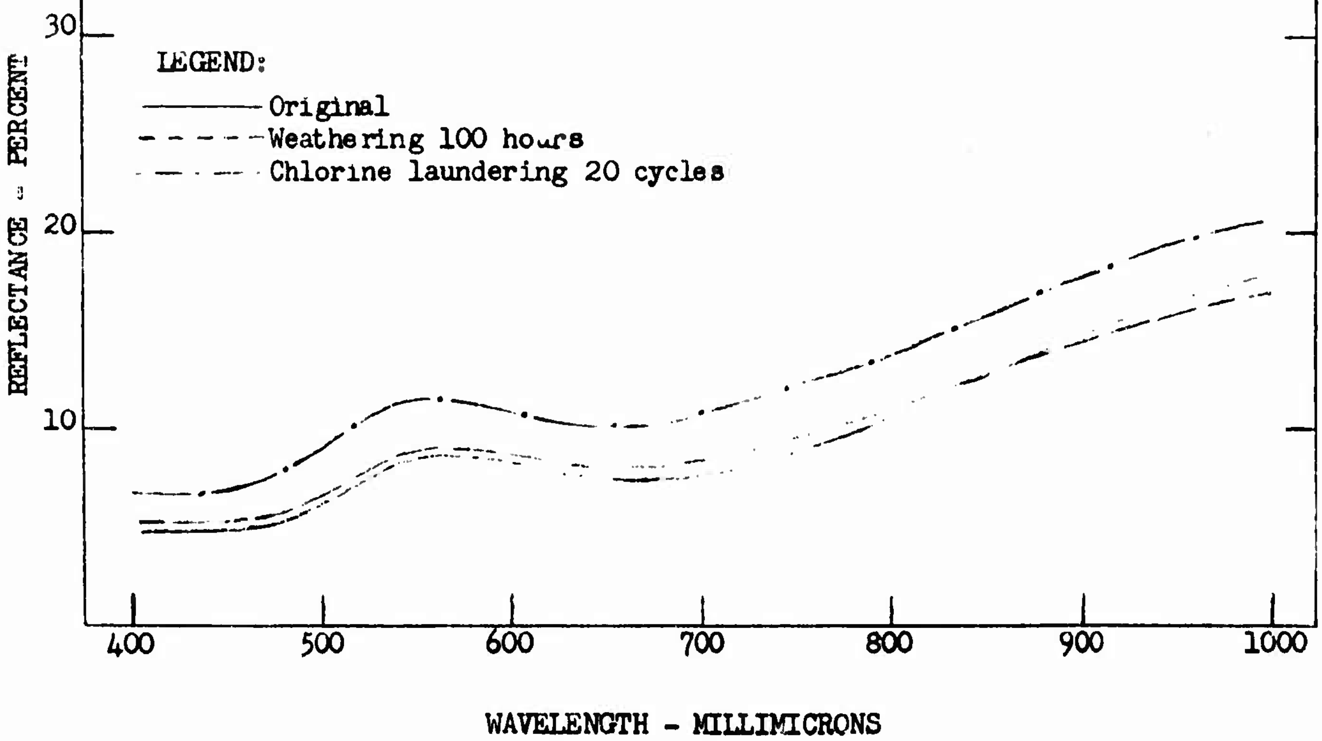


FIGURE 4: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AR.

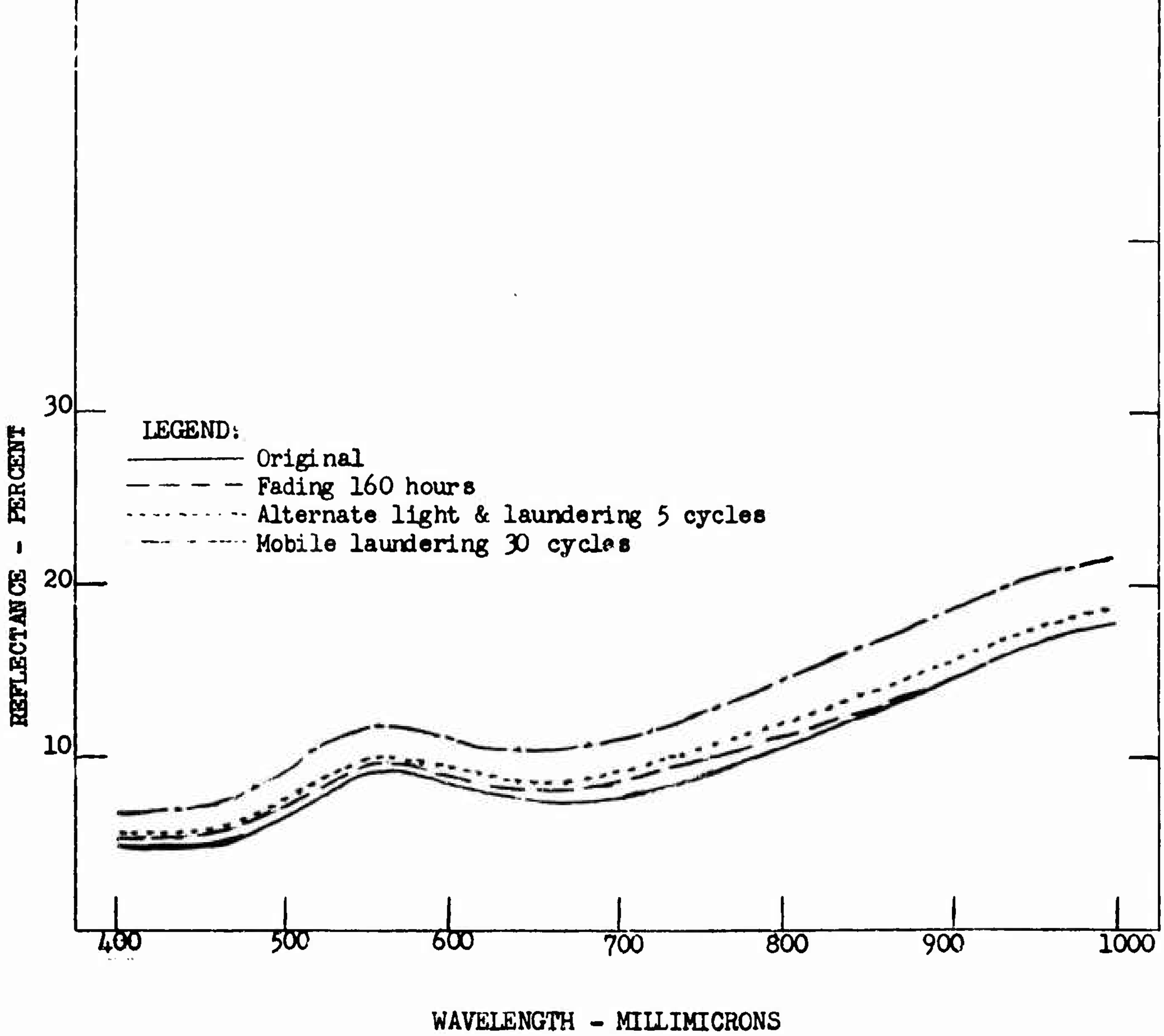


FIGURE 4a: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AR.

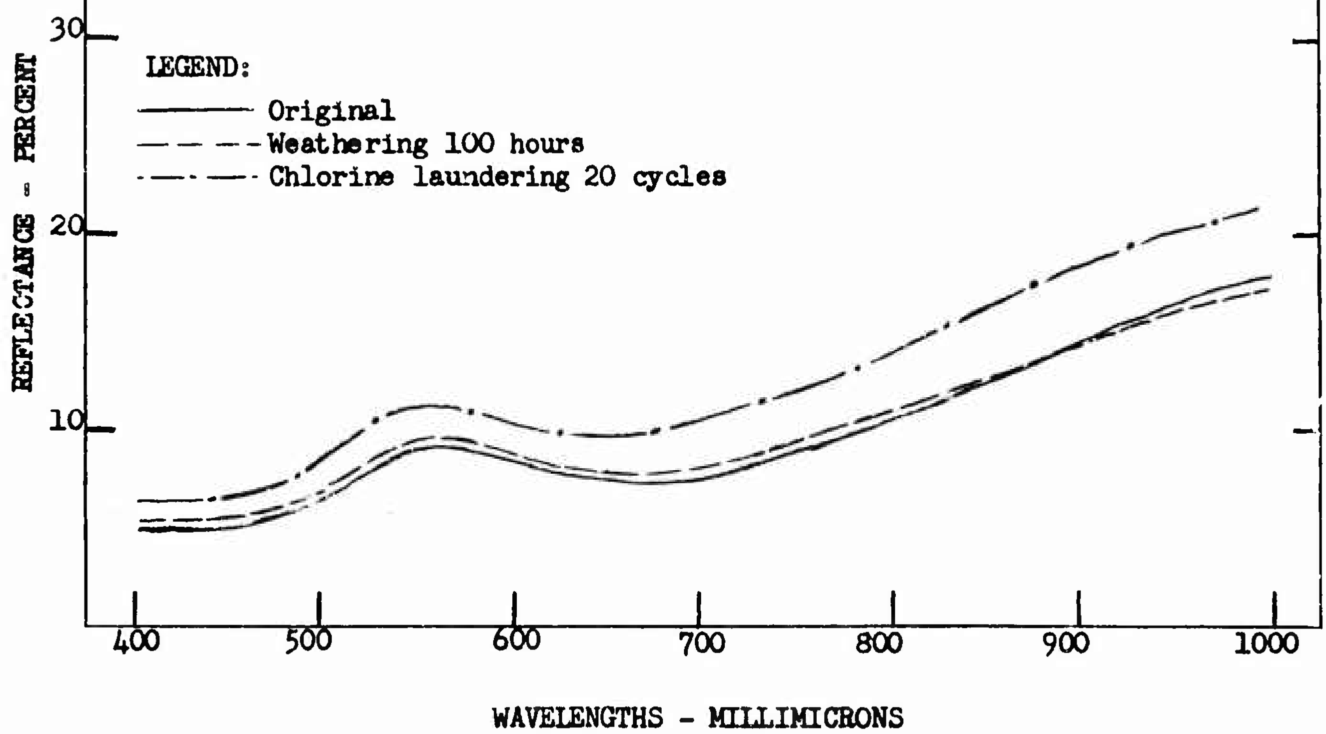


FIGURE 5: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AC.

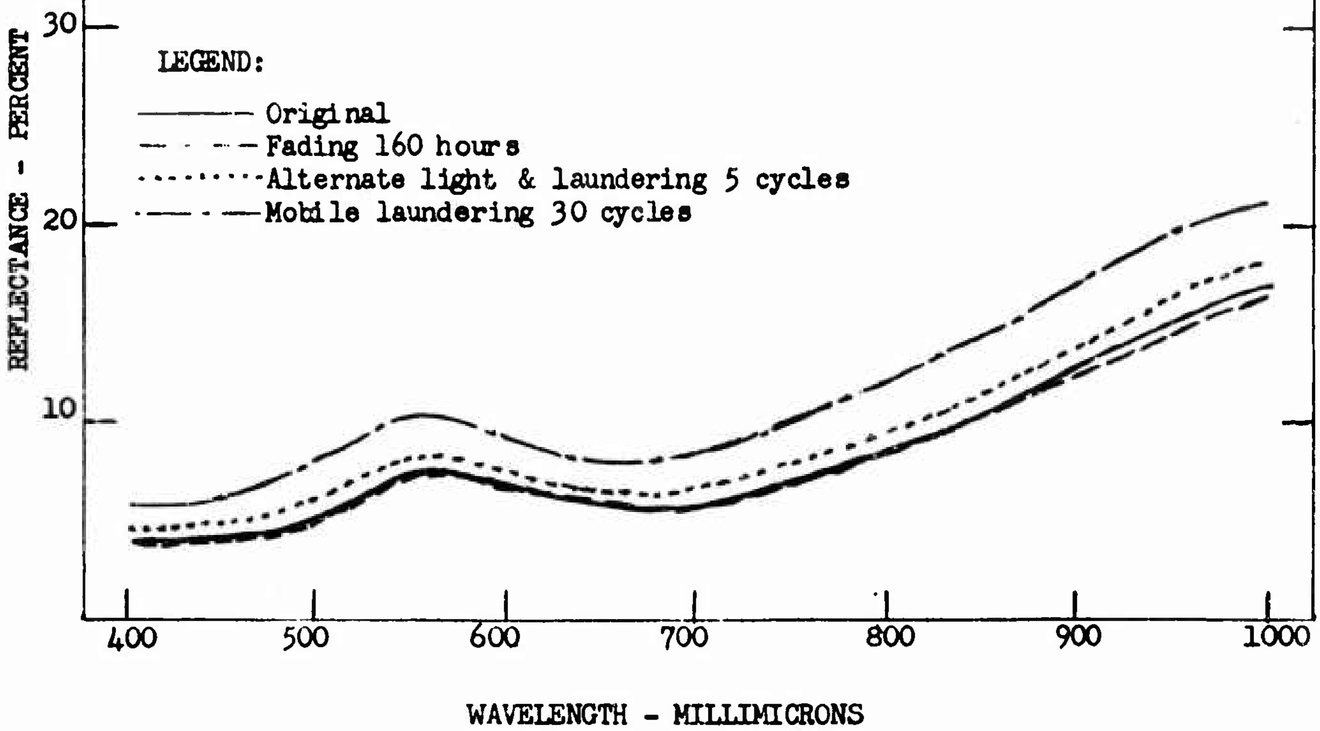


FIGURE 5a: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AC.

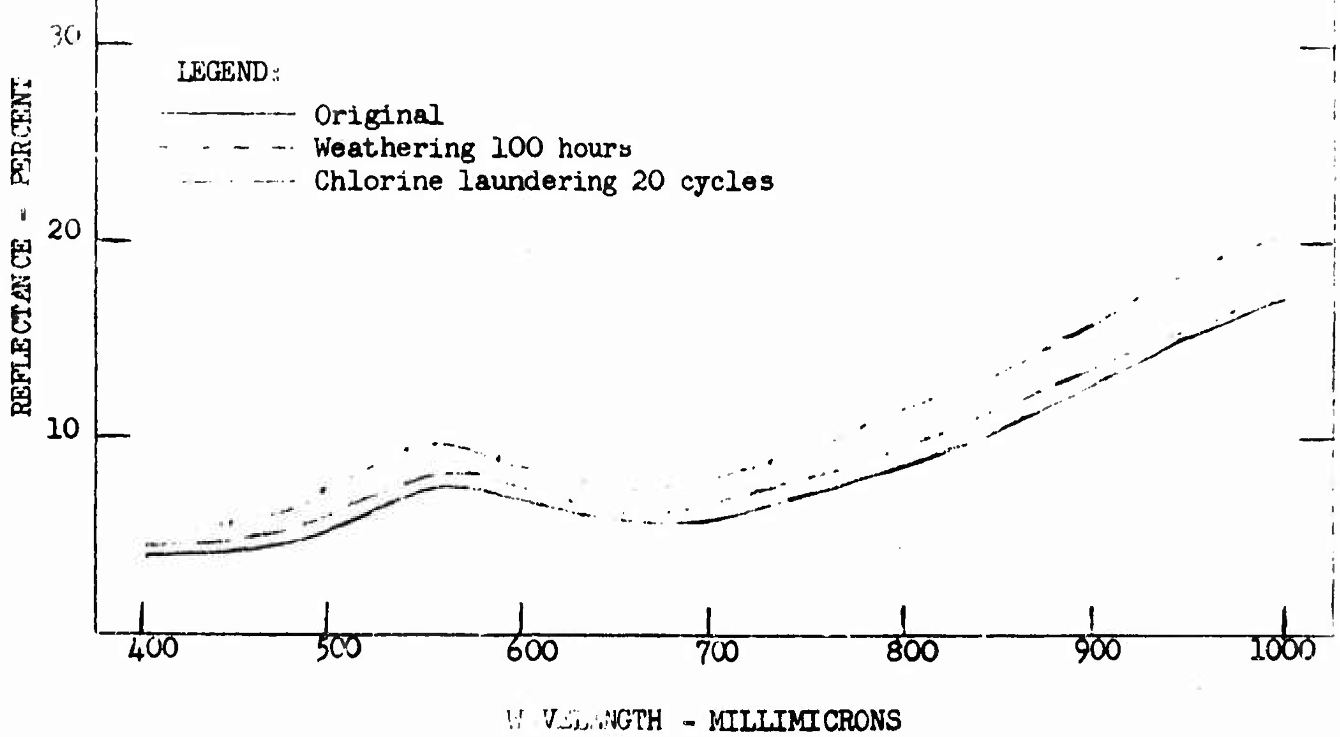
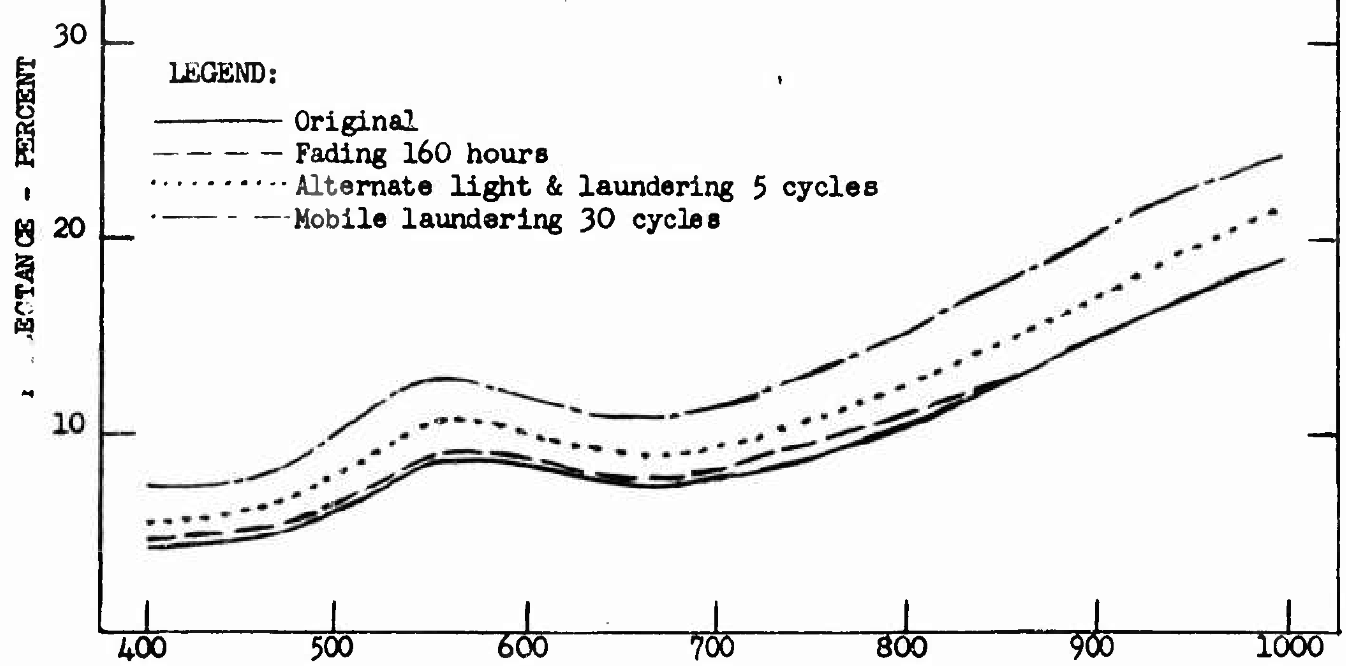
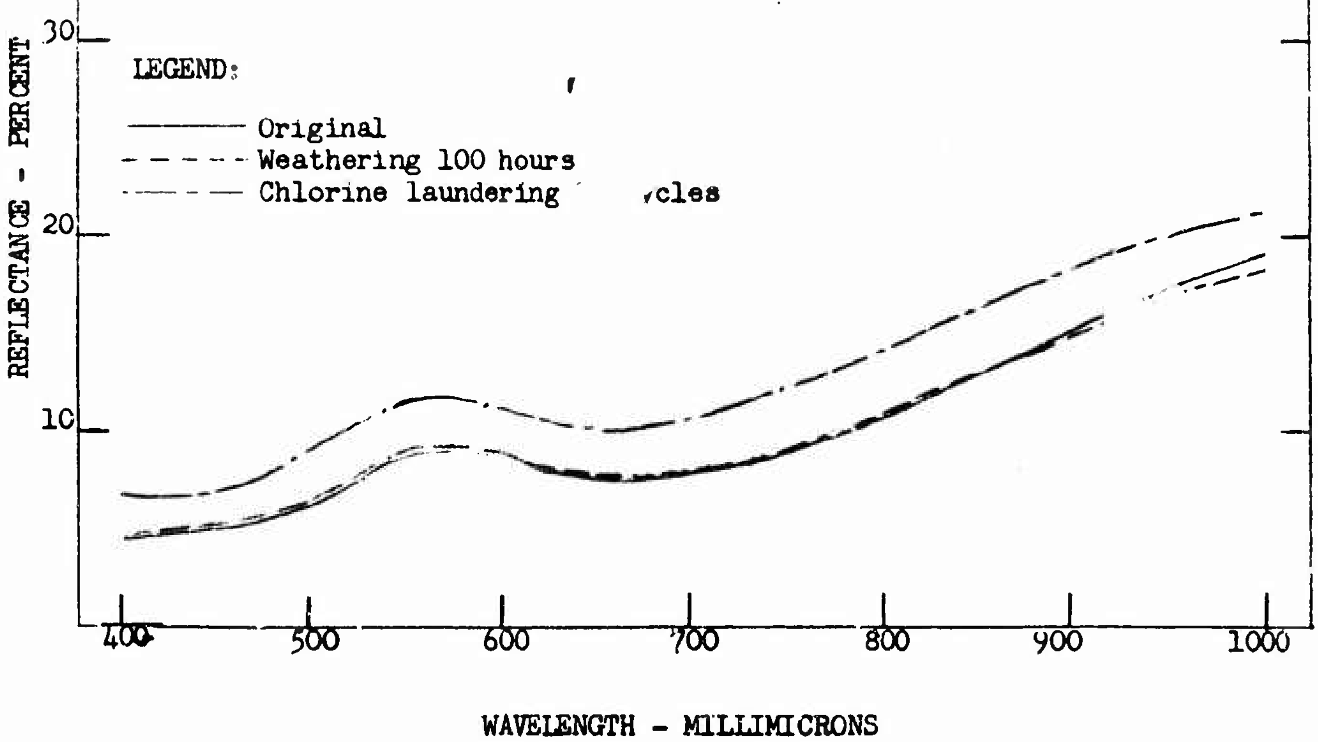


FIGURE 6: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE BO.



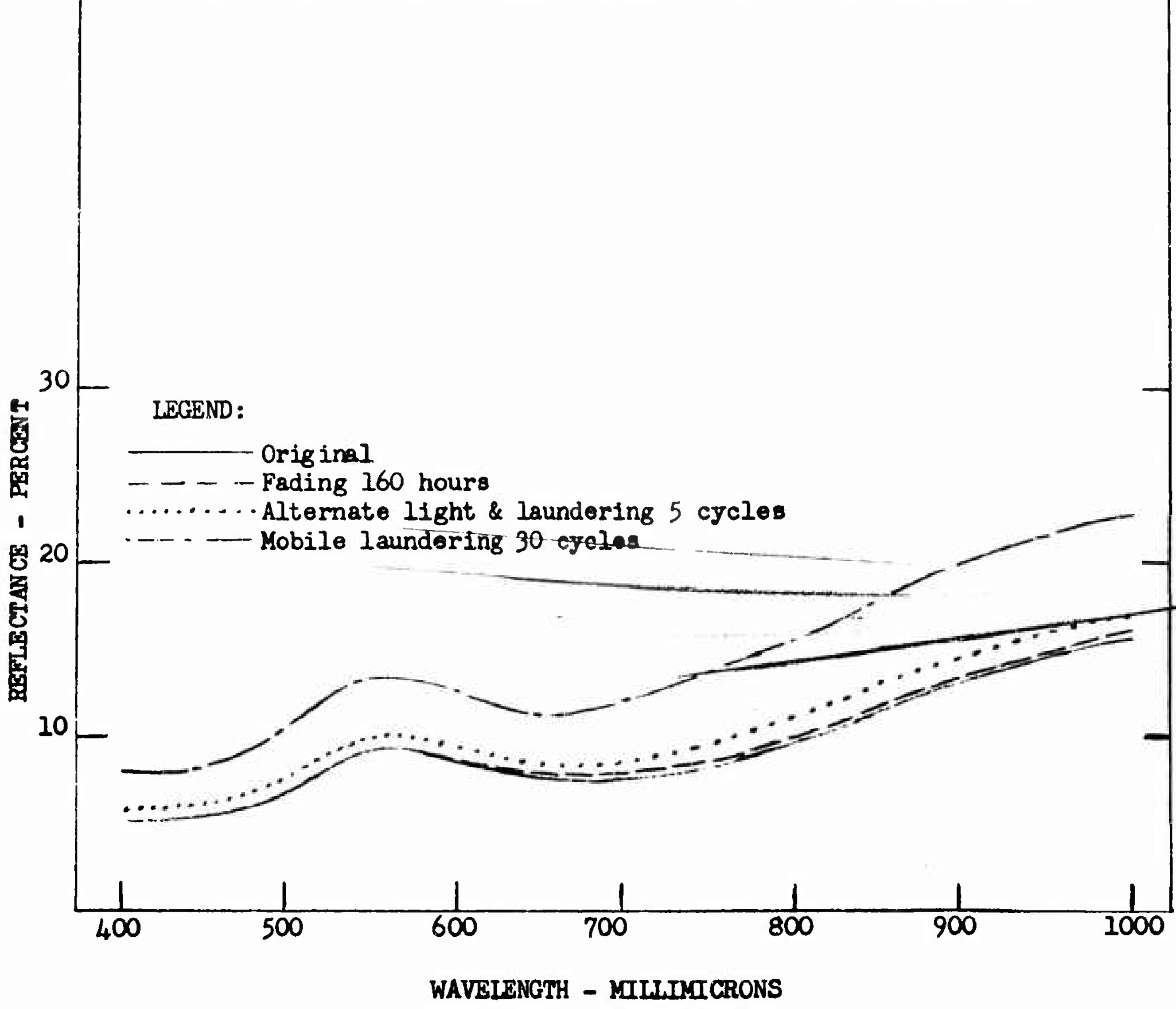
WAVELENGTH - MILLIMICRONS

FIGURE 6a: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE BO.



CONFIDENTIAL

FIGURE 7: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE BR.



CONFIDENTIAL

FIGURE 7a: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE BR.

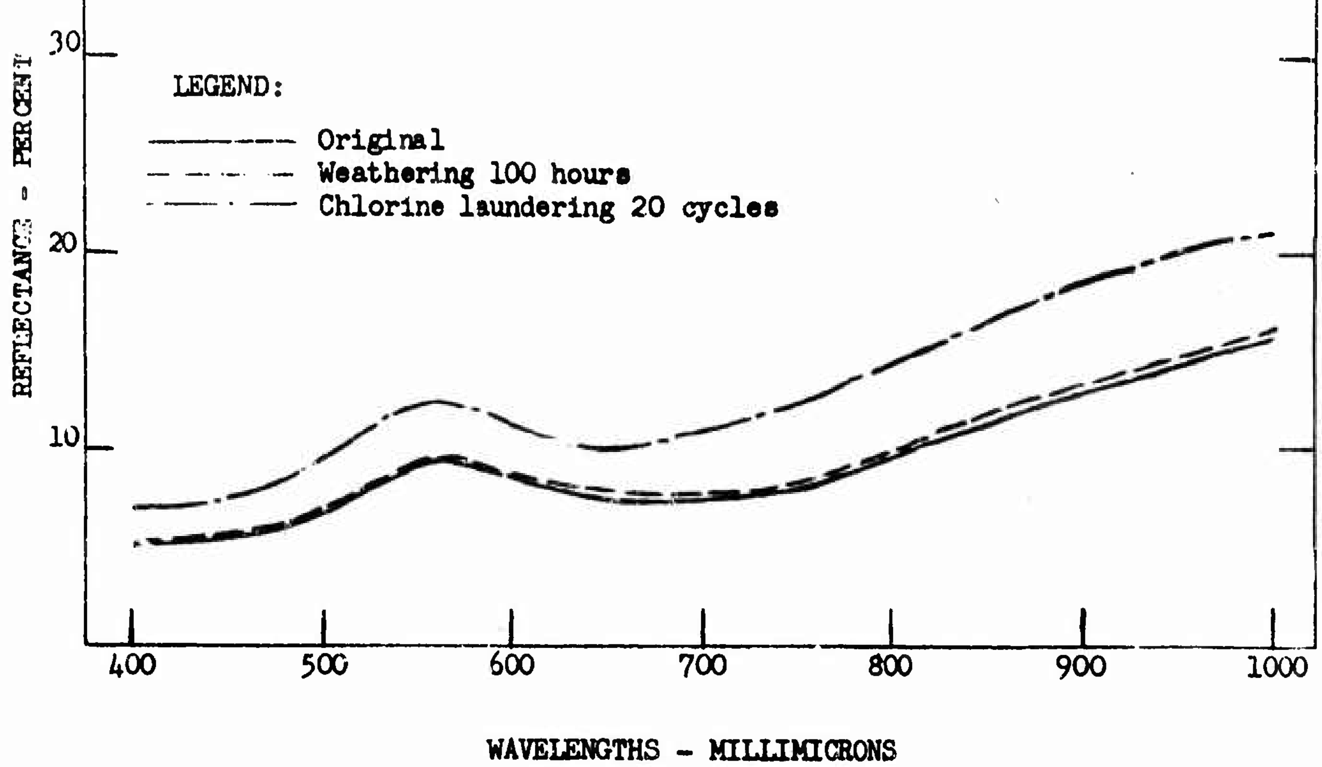
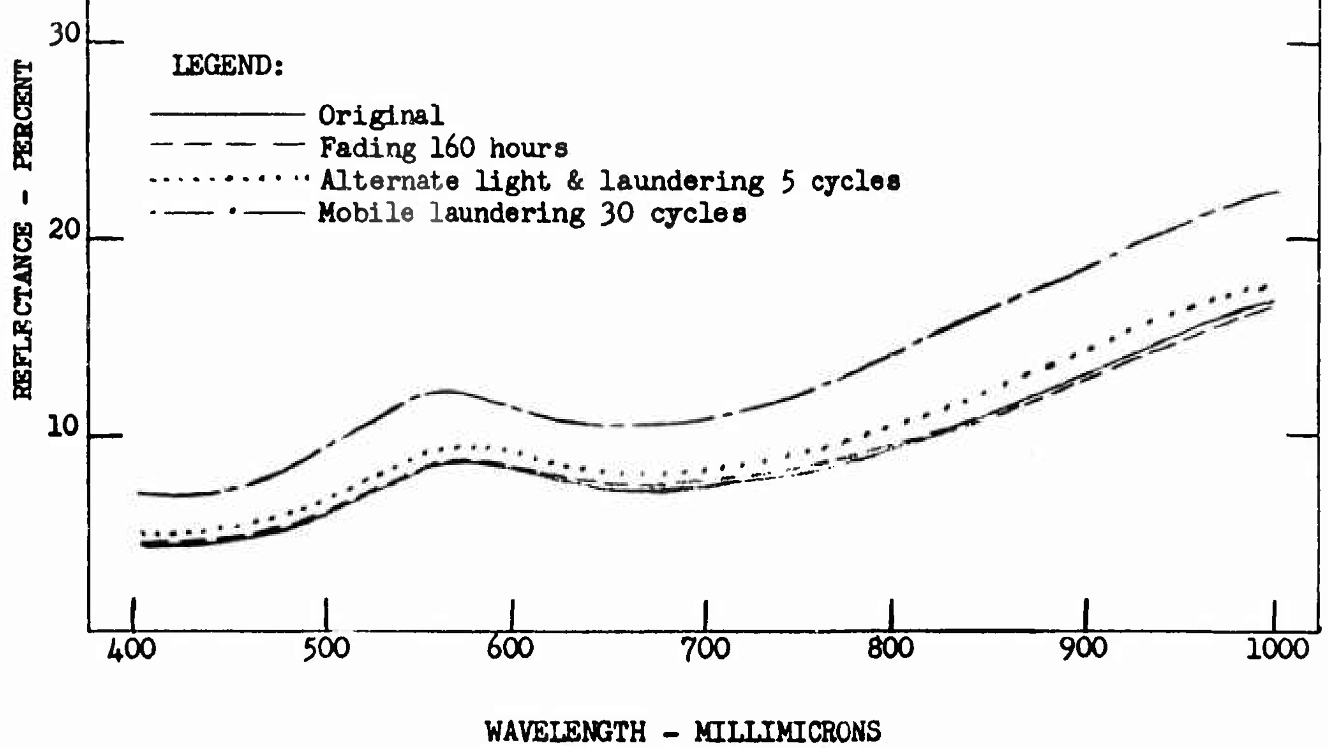
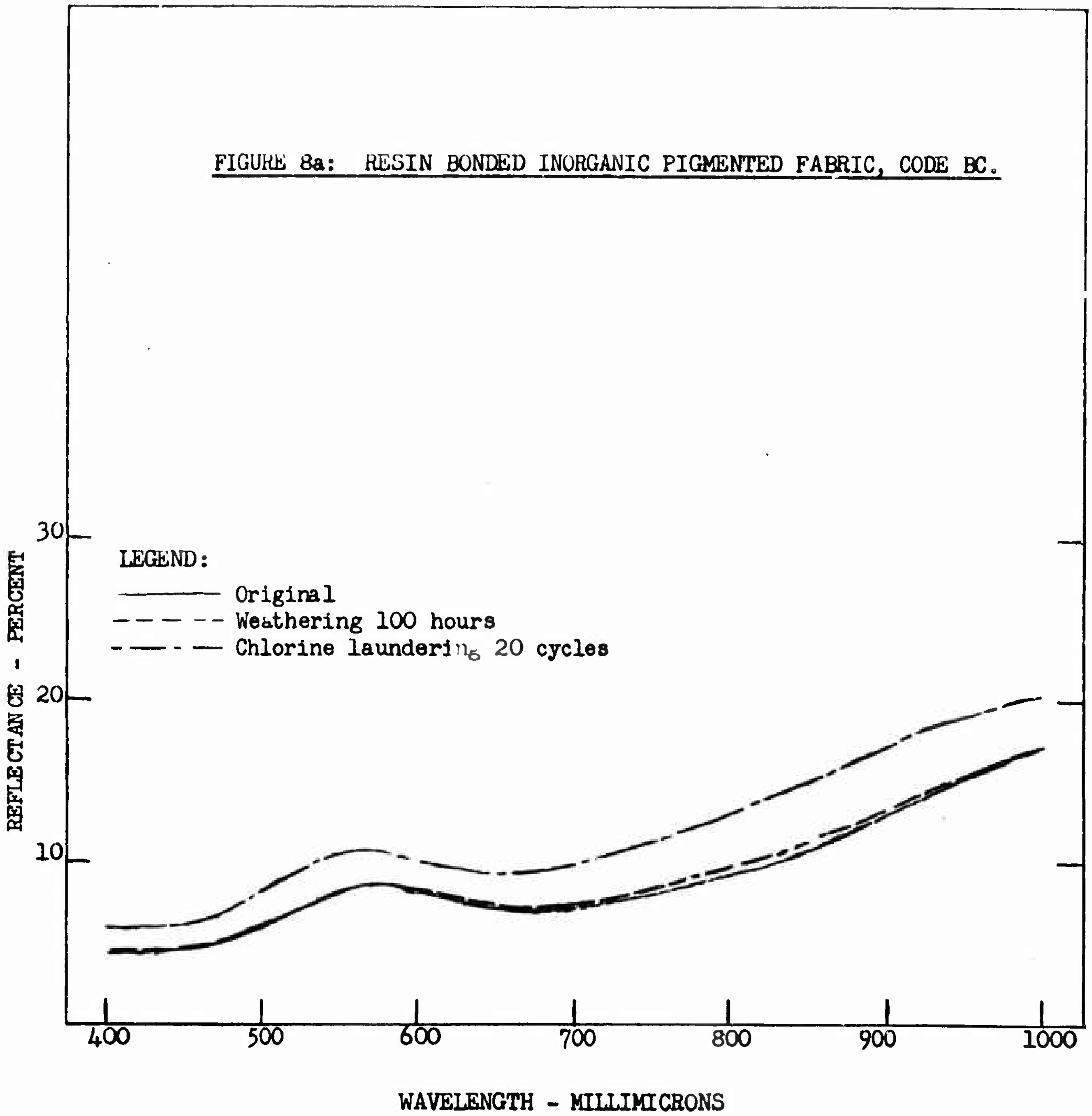


FIGURE 8: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE BC.



CONFIDENTIAL



CONFIDENTIAL

FIGURE 9: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE CC.

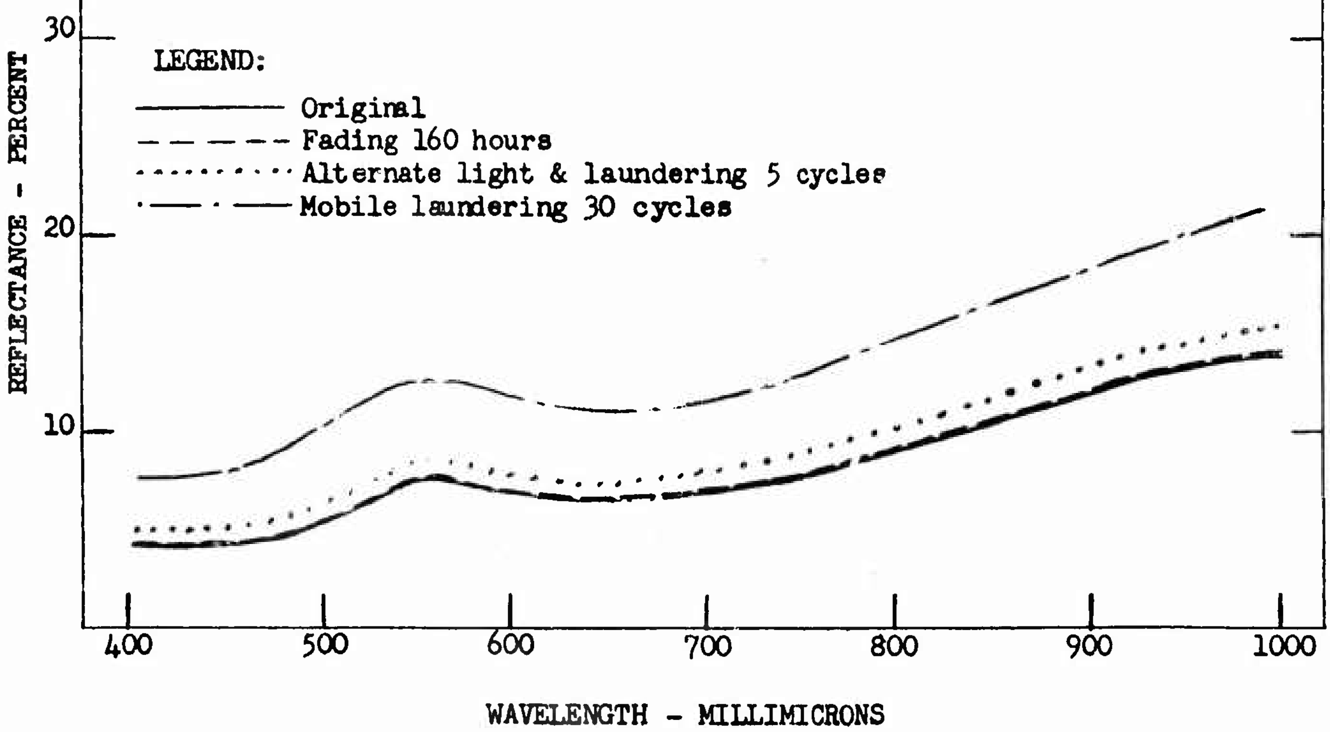


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FIGURE 9a: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE CC.

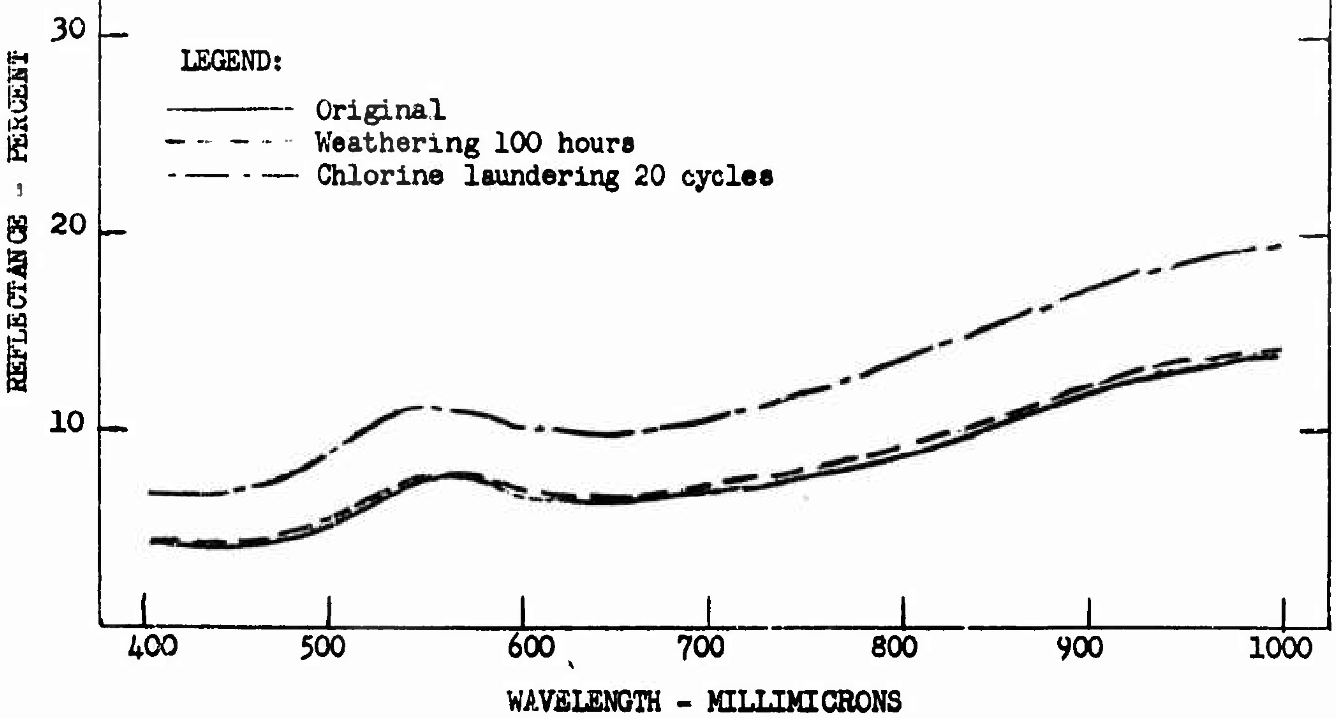

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FIGURE 10: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE DO.

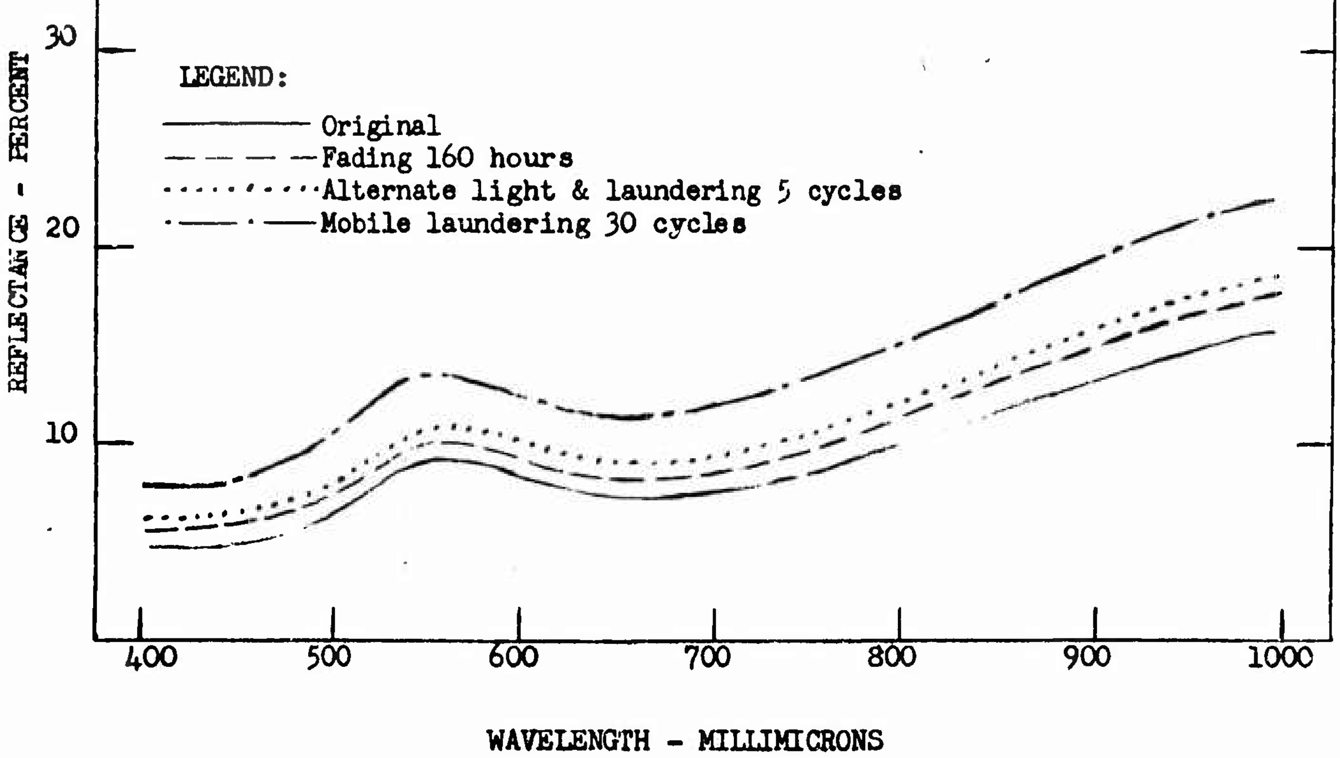

FIGURE 10a: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE DO.

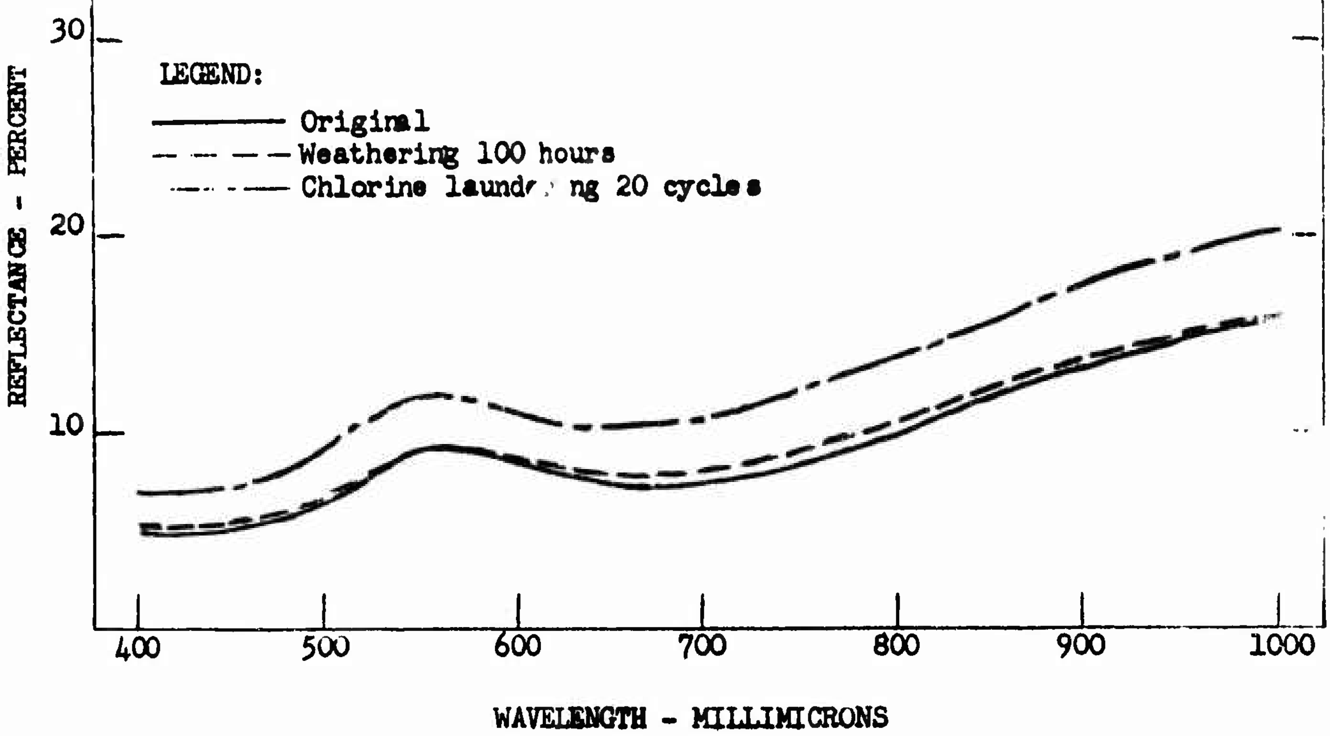

FIGURE 11: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE DC.

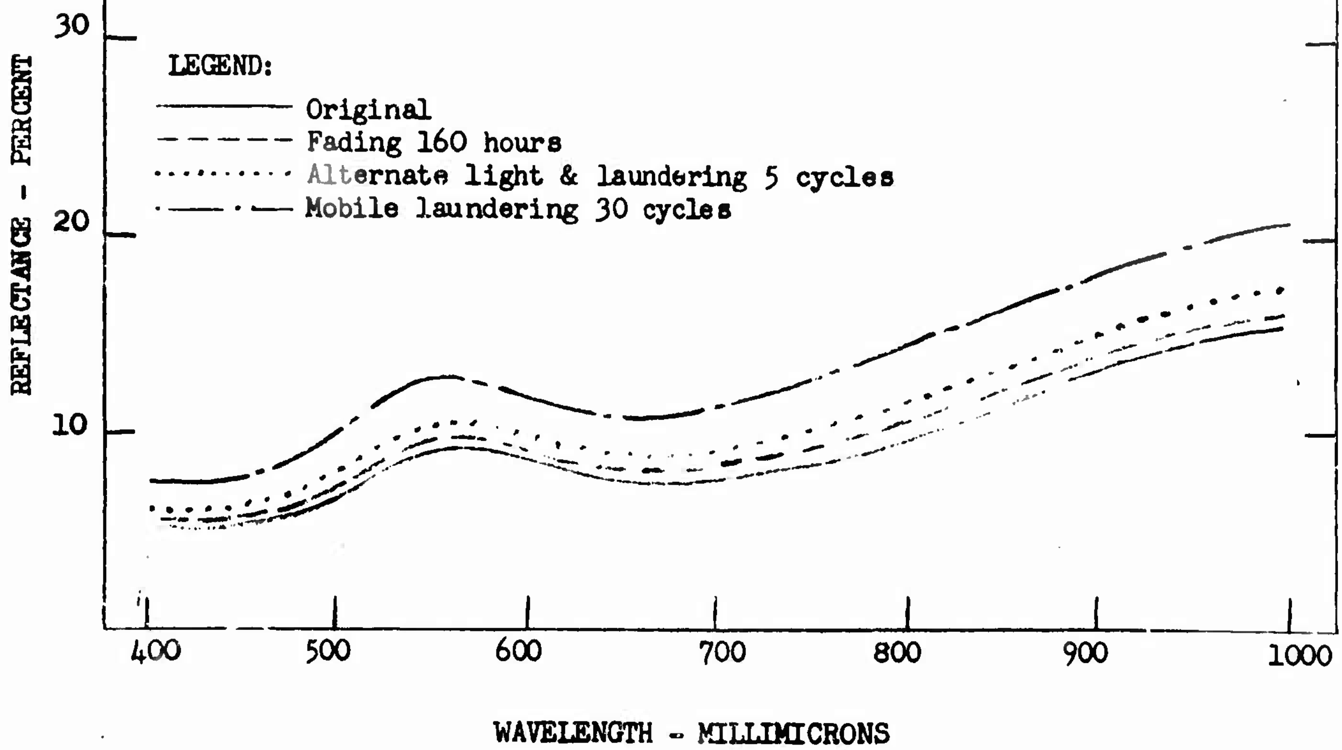

FIGURE 11a: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE DC.

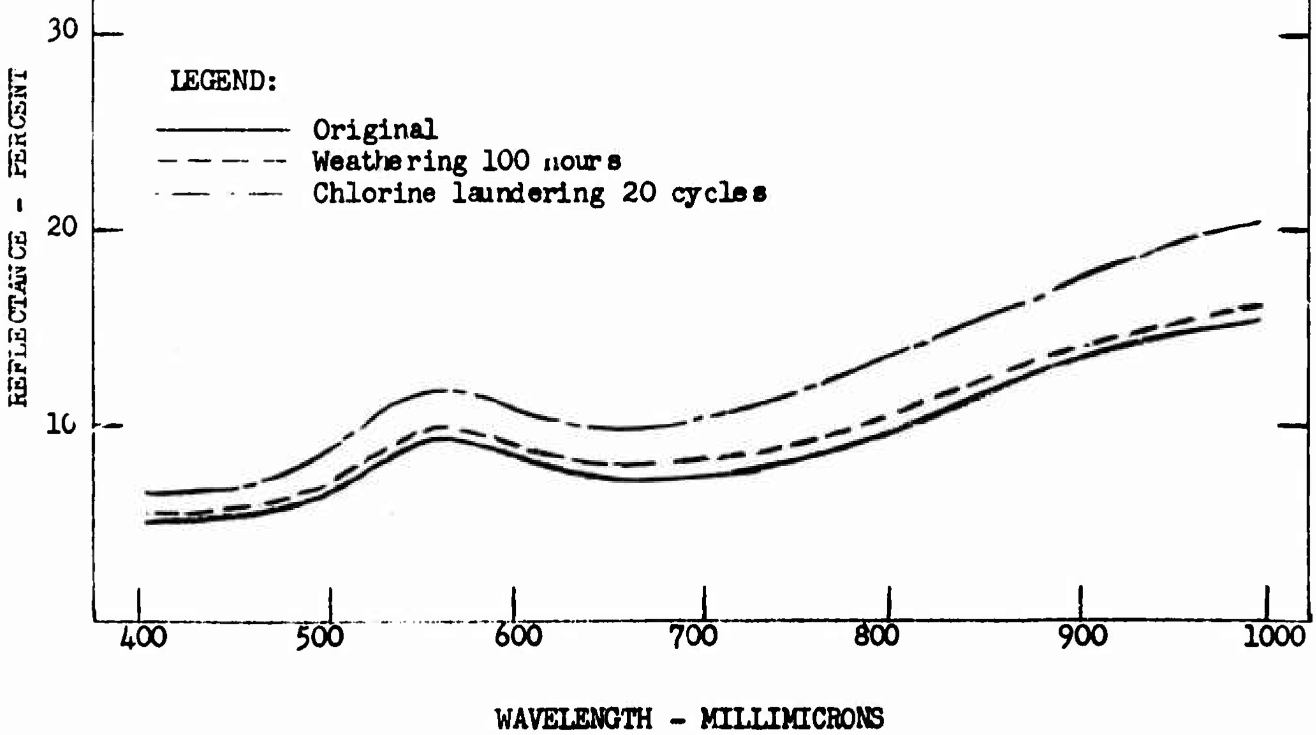

FIGURE 12: PRESENT VAT DYED STANDARD FOR OLIVE GREEN 107, CODE ST.

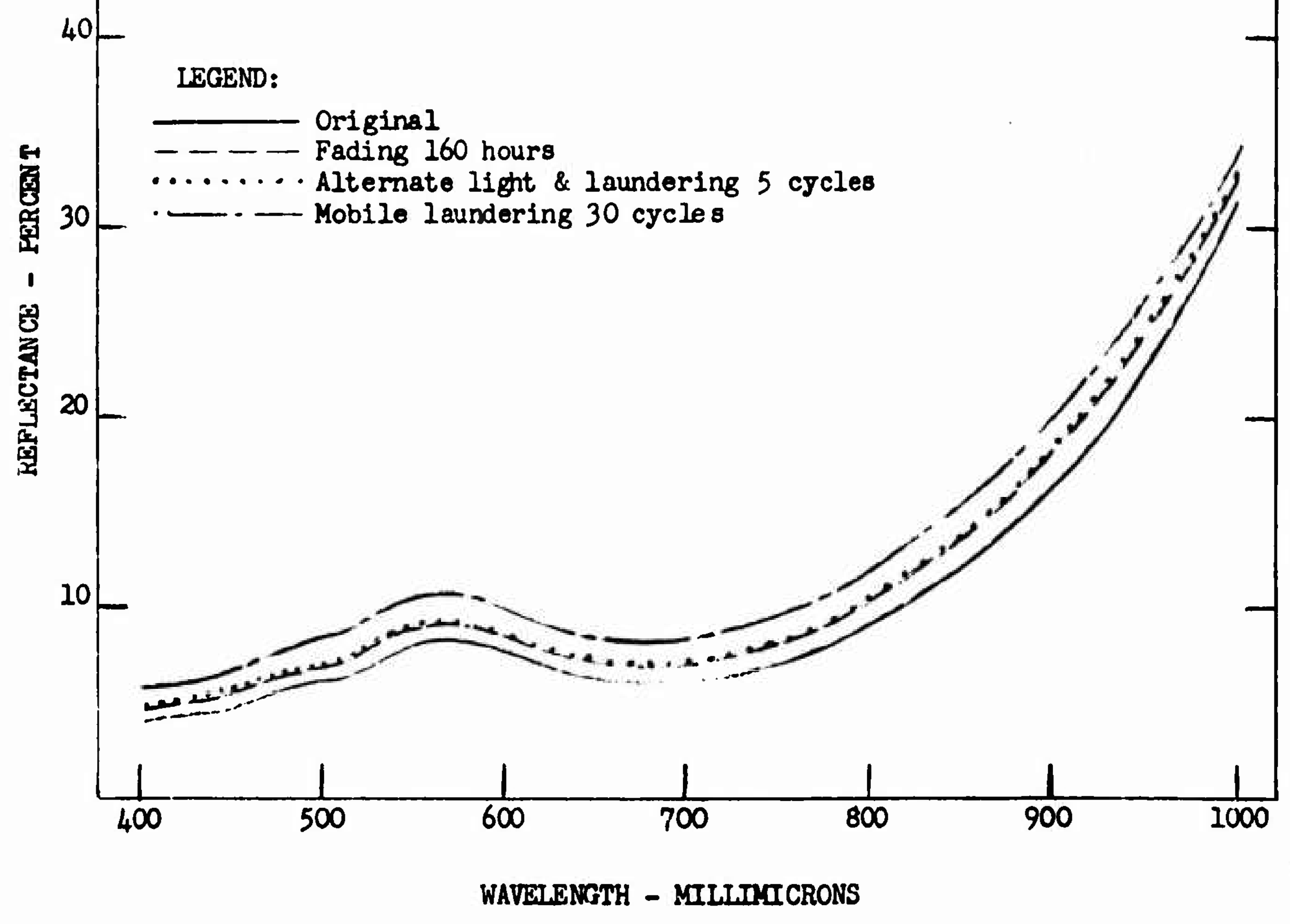

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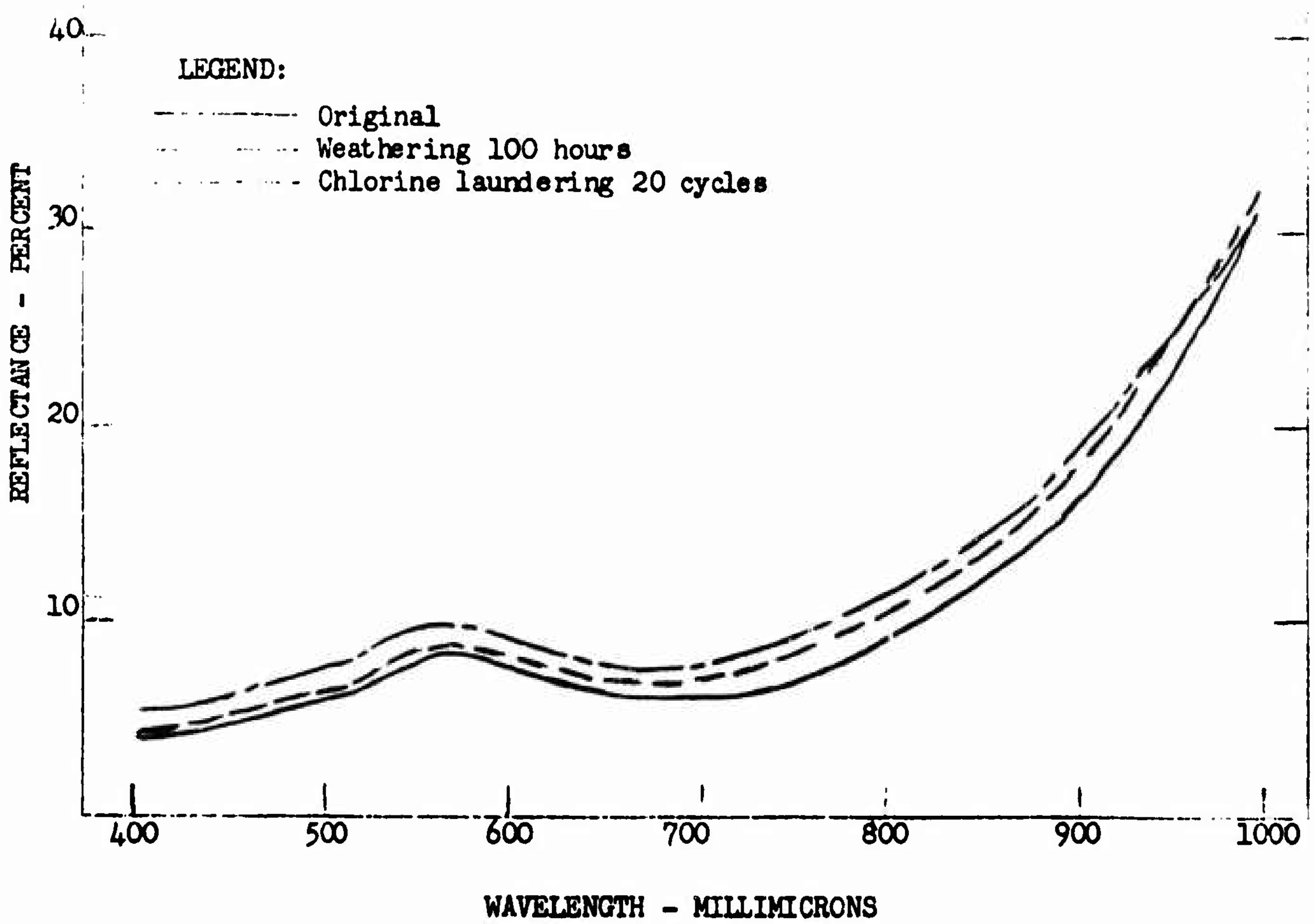
FIGURE 12a: PRESENT VAT DYED STANDARD FOR OLIVE GREEN 107, CODE ST.



CONFIDENTIAL

FIGURE 13: NEW QUARTERMASTER DEVELOPED VAT DYED FABRIC, CODE CV.

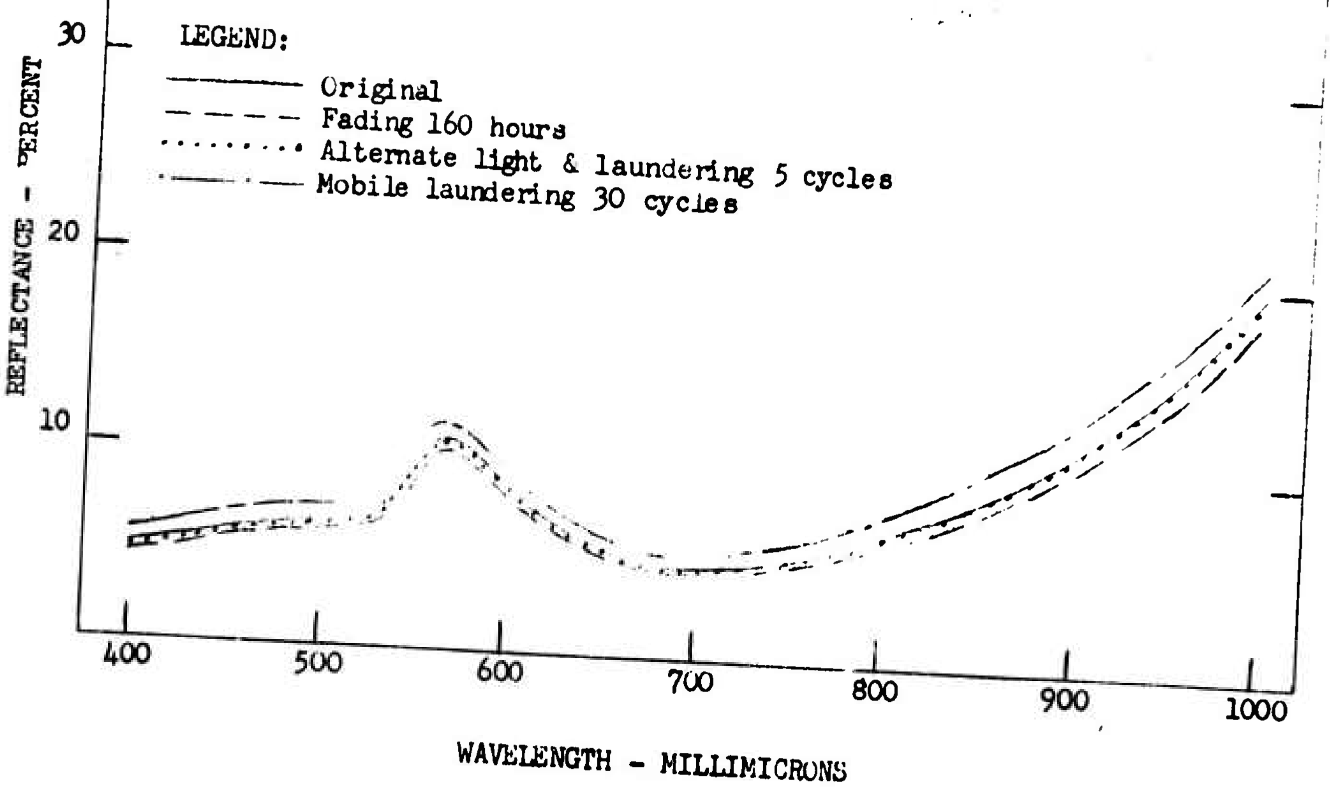


FIGURE 13a: NEW QUARTERMASTER DEVELOPED VAT DYED FABRIC, CODE CV.

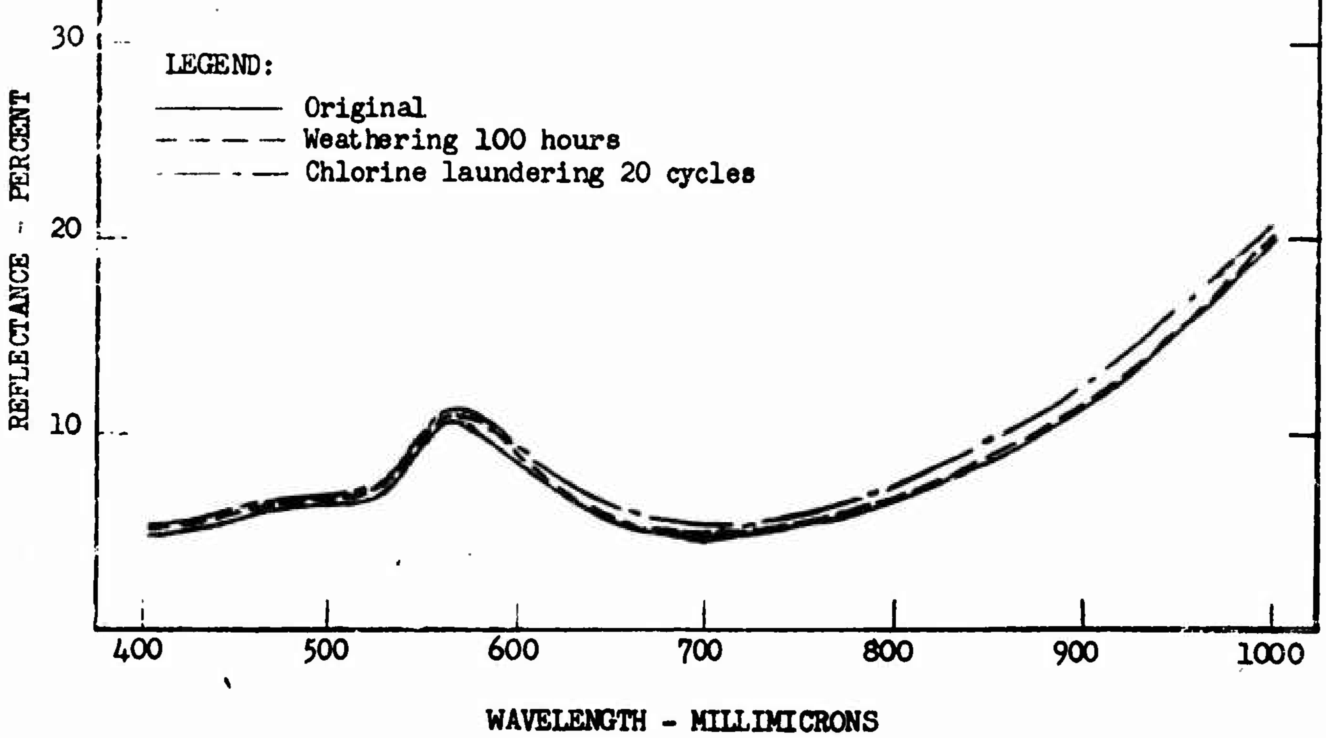
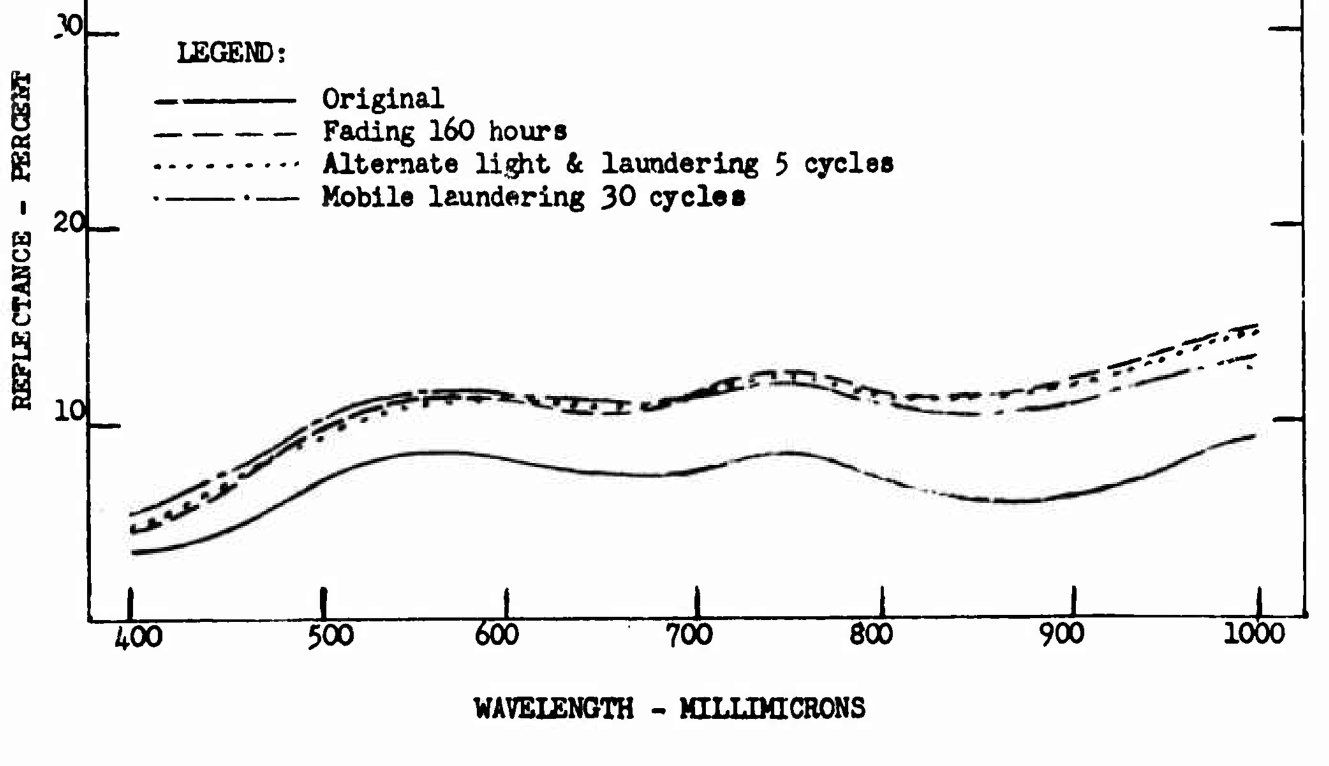


FIGURE 14: SULFUR DYED FABRIC, CODE S.



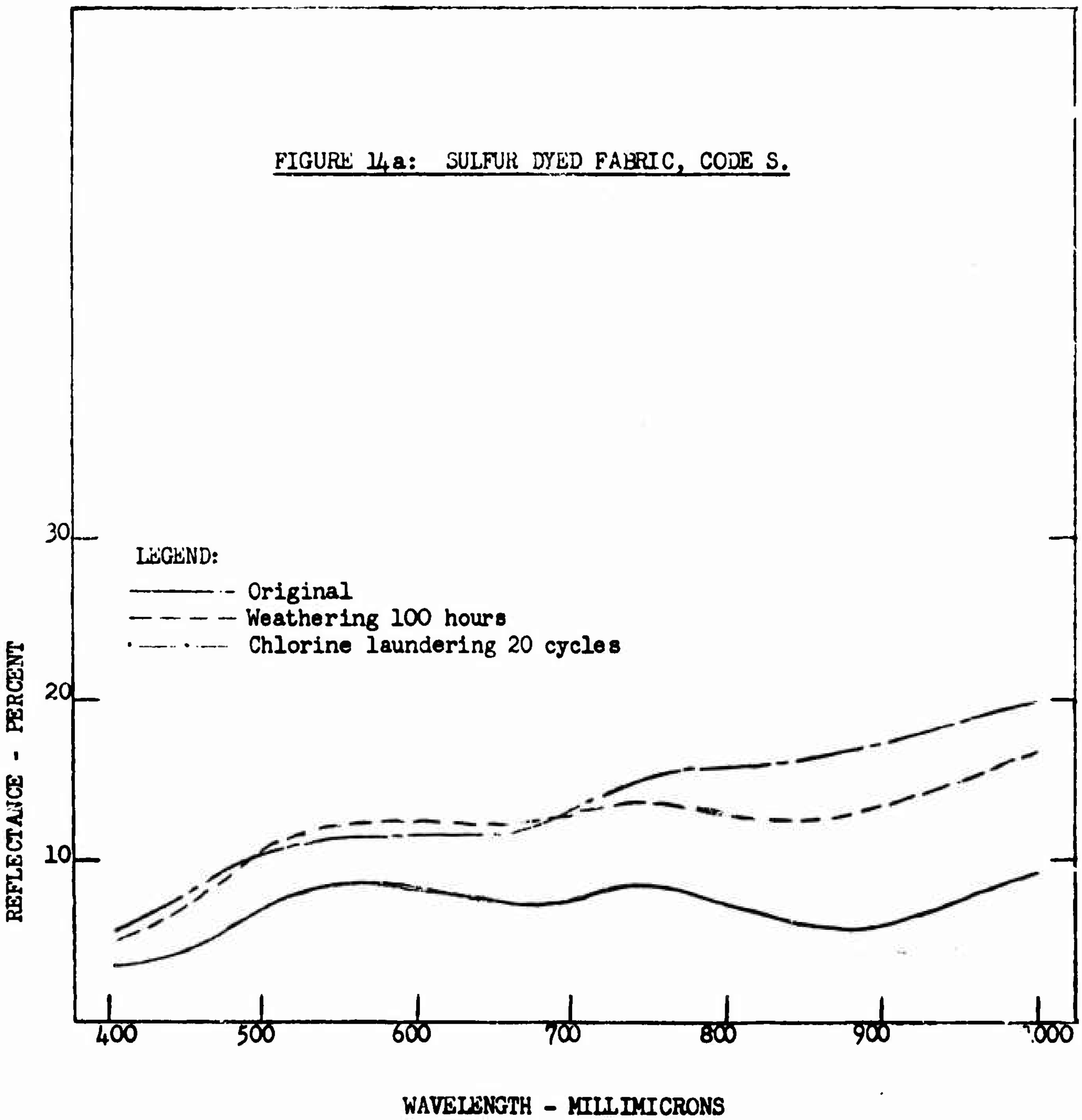


FIGURE 14a: SULFUR DYED FABRIC, CODE S.
LEGEND:
Original
Weathering 100 hours
Chlorine laundering 20 cycles
30
20
10
REFLECTANCE - PERCENT
400
500
600
700
800
900
1000
WAVELENGTH - MILLIMICRONS

PART D: SPECTRAL REFLECTANCE CURVES OF TEST FABRICS IN THE SPECTRAL RANGE FROM 1.0 MICRON TO 4.2 MICRONS.

FIGURE 15: PRESENT VAT DYED STANDARD FOR OLIVE GREEN 107, CODE ST.

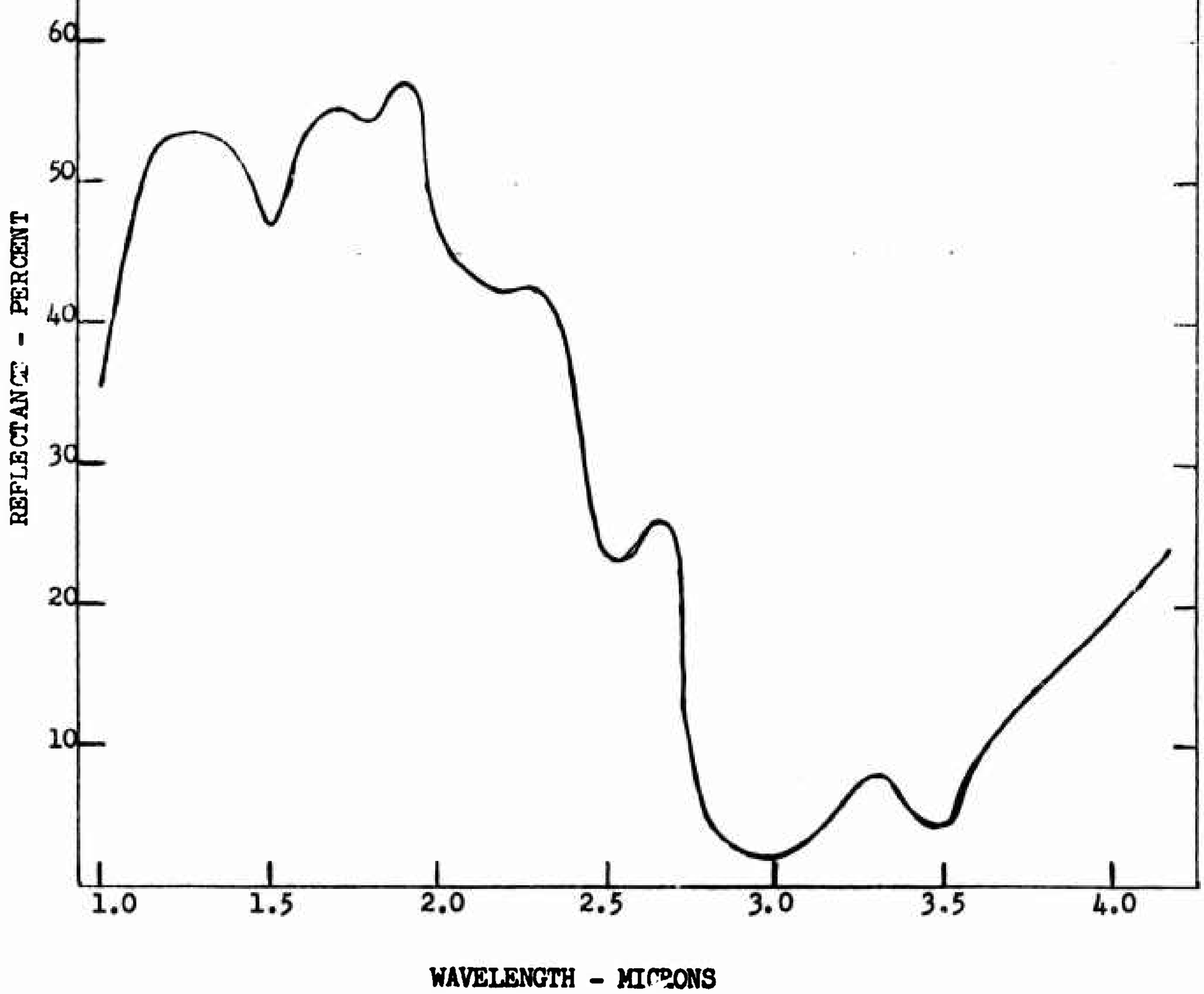


FIGURE 16: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AR.

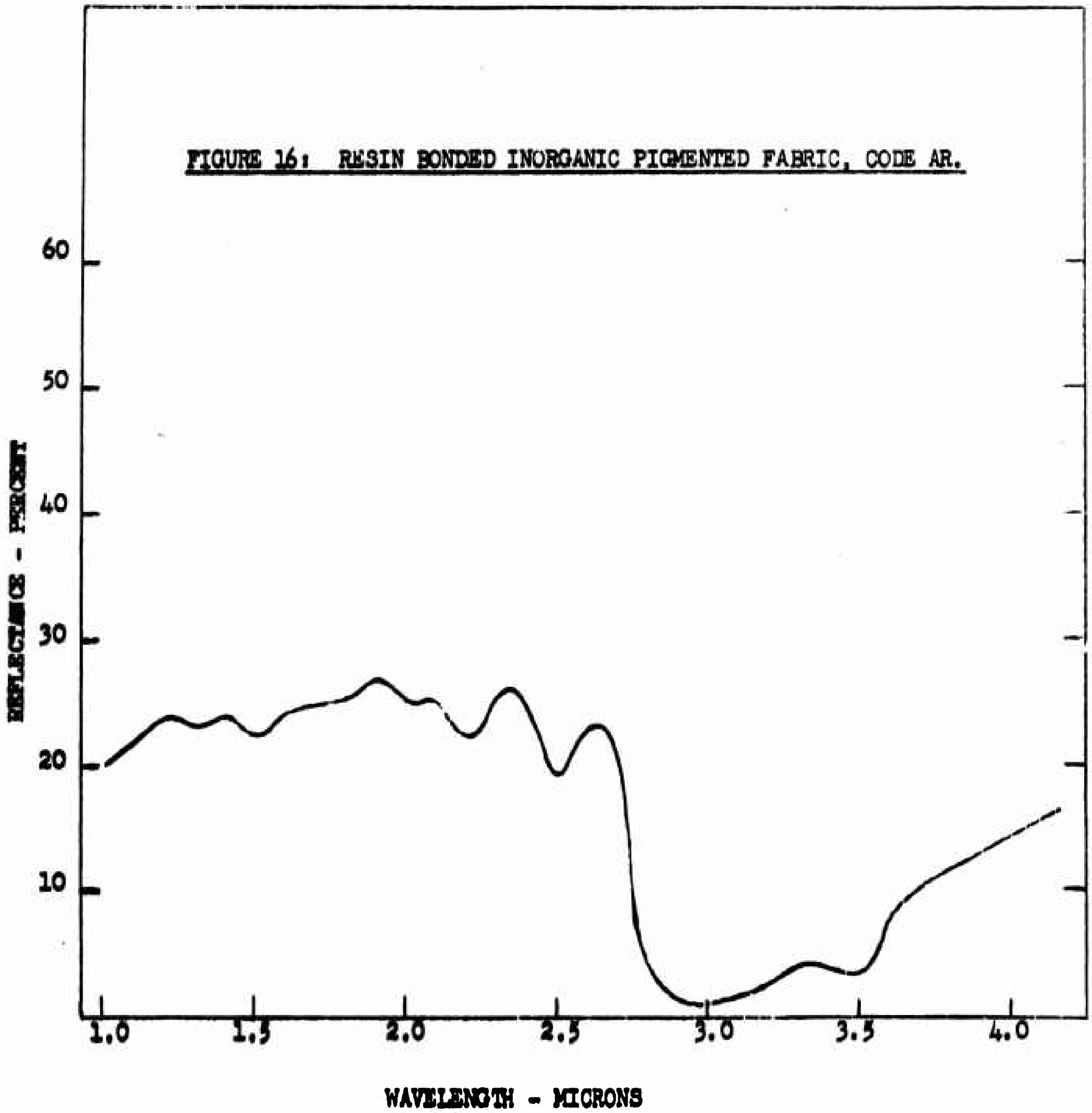


FIGURE 17: NEW QUARTERMASTER DEVELOPED VAT DYED FABRIC, CODE CV.

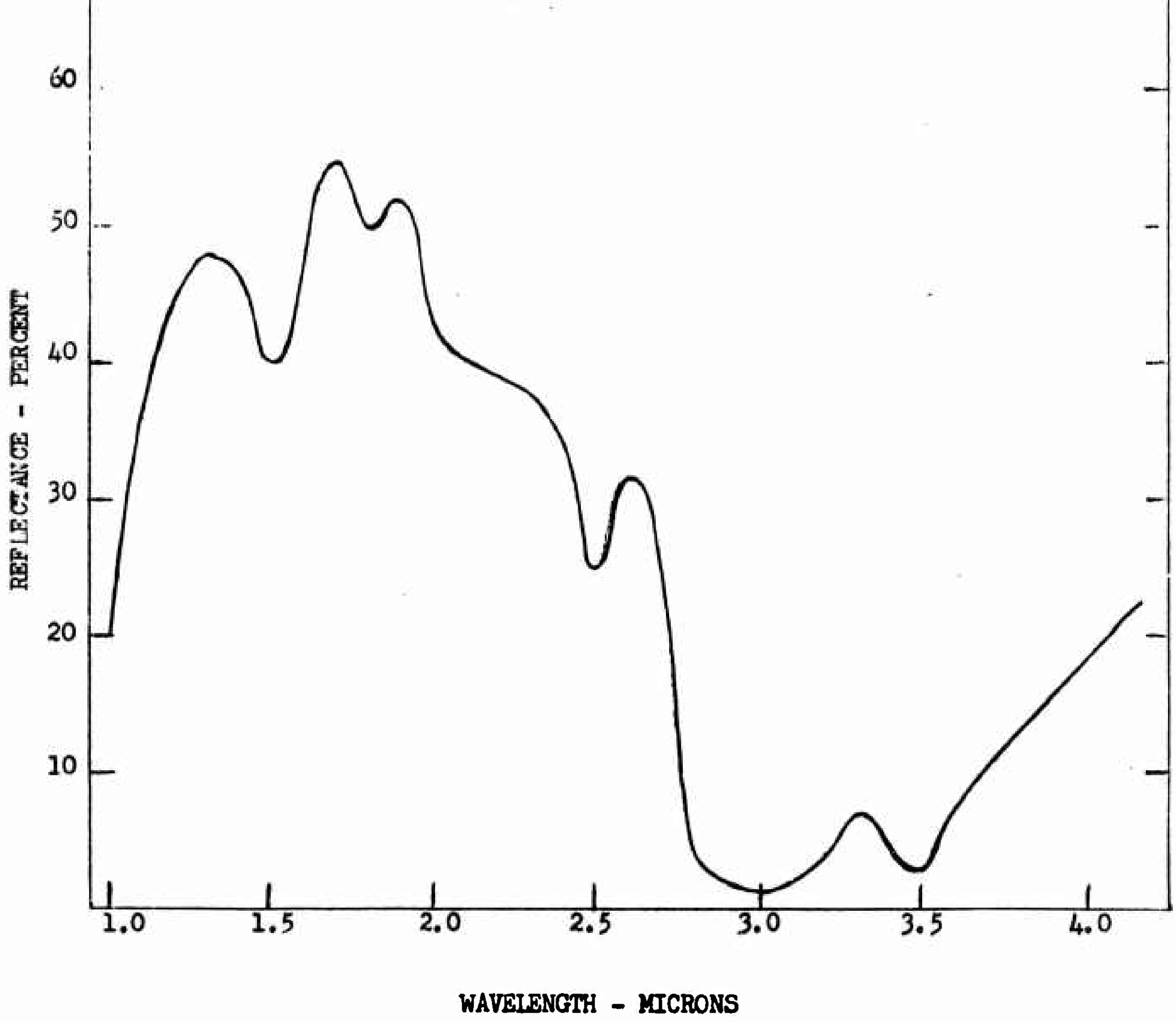
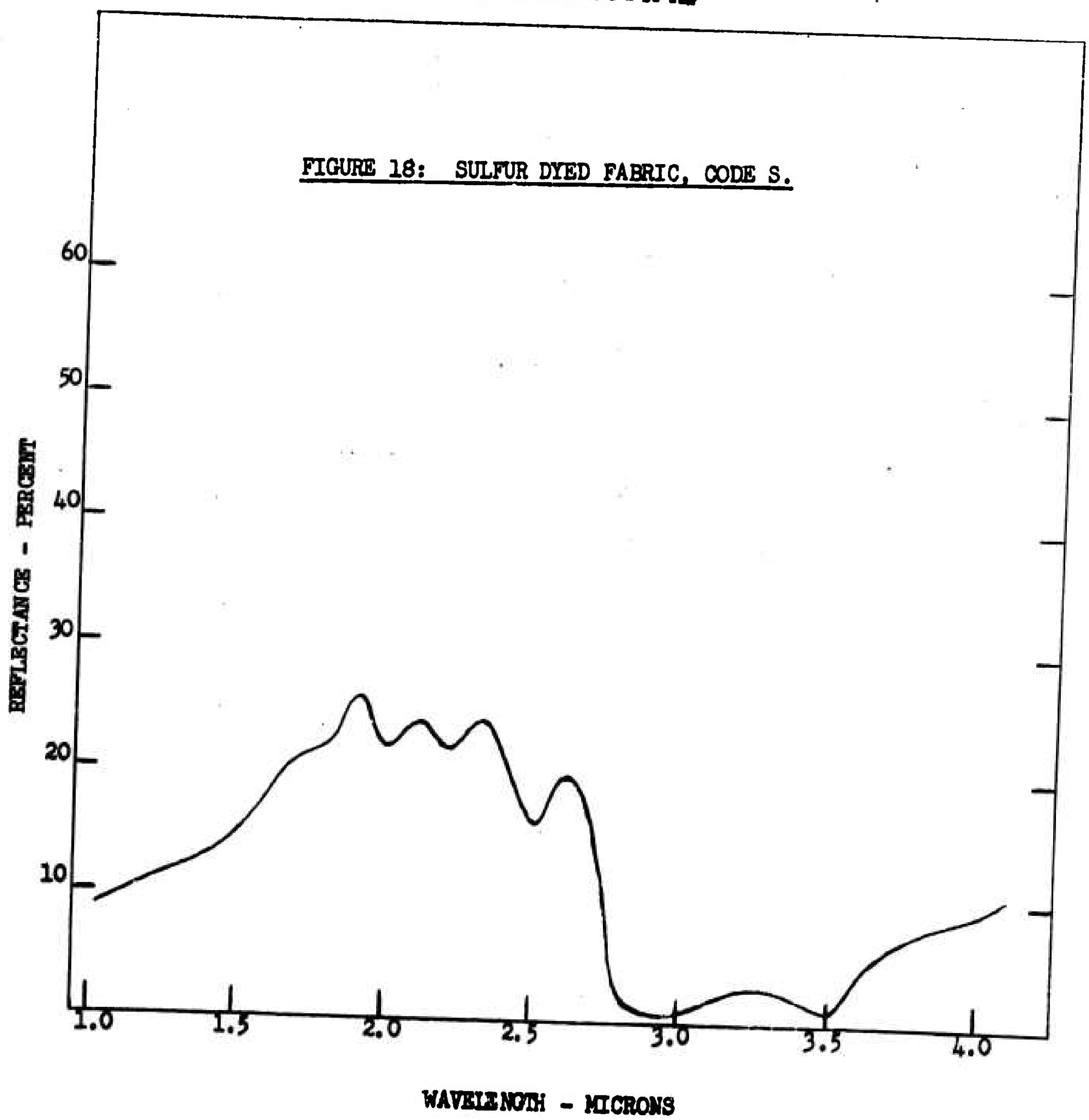


FIGURE 18: SULFUR DYED FABRIC, CODE S.



PART E: SPECTRAL REFLECTANCE CURVES OF TEST FABRICS SHOWING EFFECTS OF IMPREGNITE XXCC-3, FROM 400 MILLIMICRONS TO 1000 MILLIMICRONS.

FIGURE 19: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE AR.

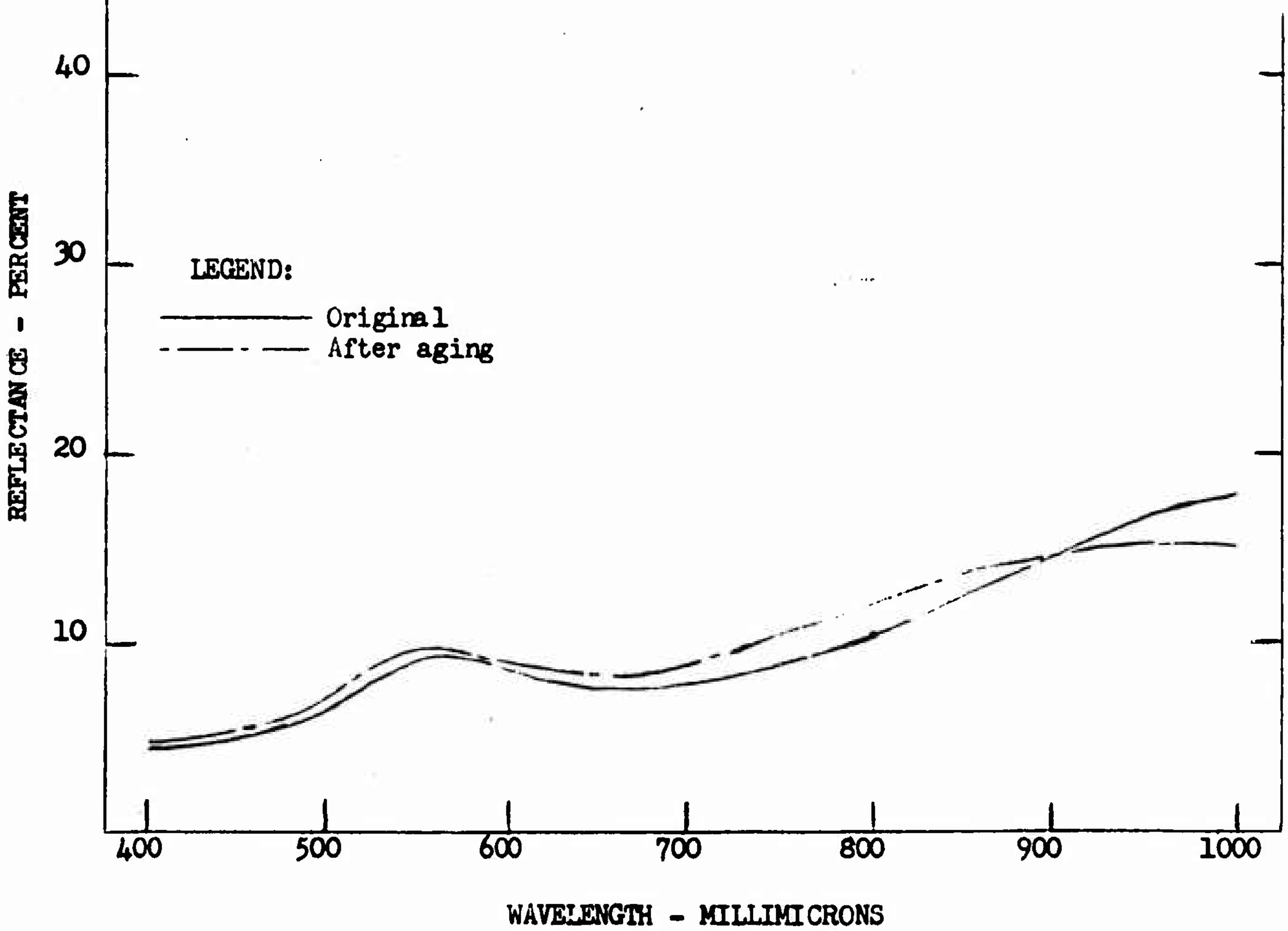


FIGURE 20: RESIN BONDED INORGANIC PIGMENTED FABRIC, CODE BR.

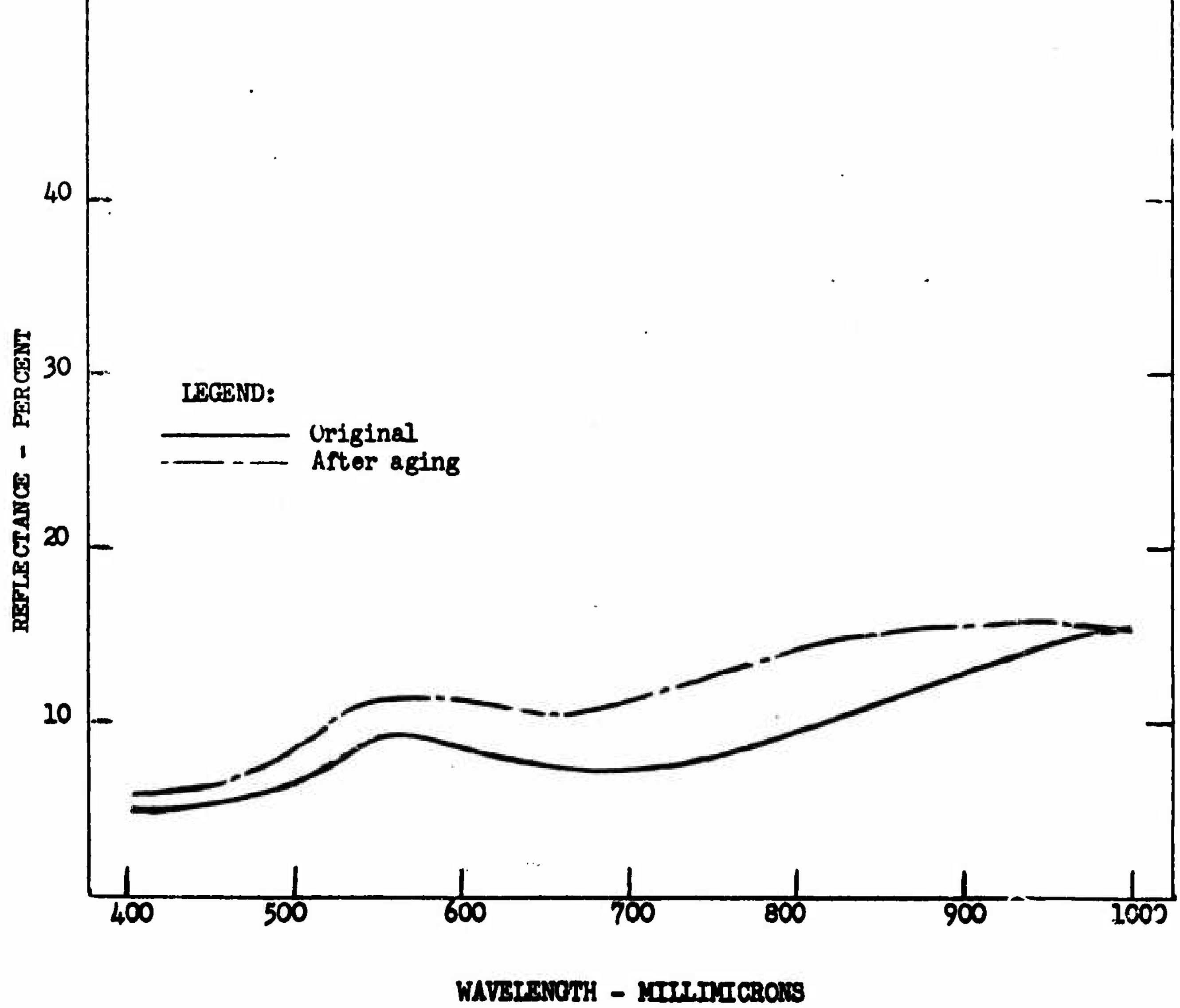


FIGURE 21: PRESENT VAT DYED STANDARD FOR OLIVE GREEN 107, CODE ST.

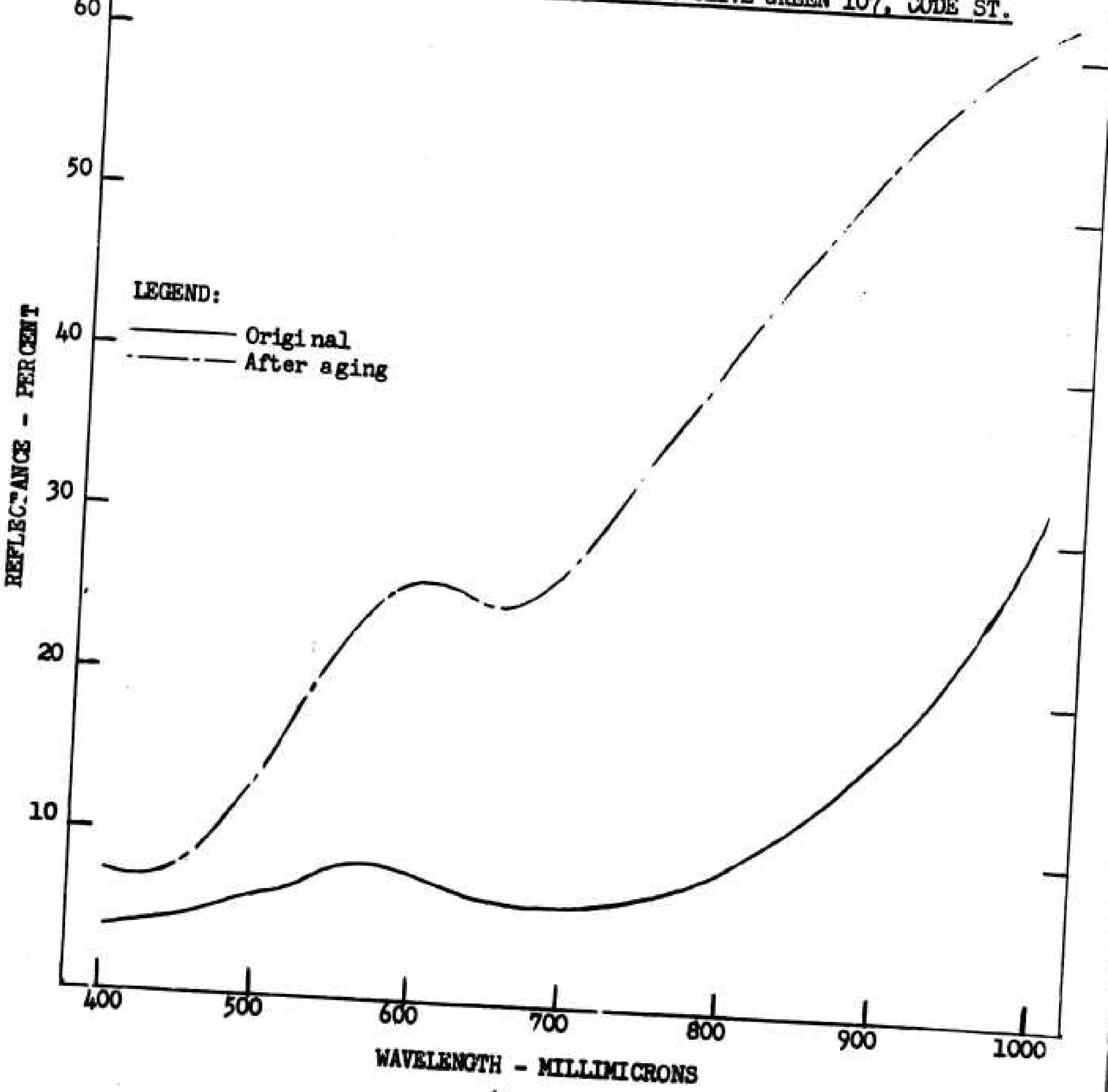


FIGURE 22: NEW QUARTERMASTER DEVELOPED VAT DYED FABRIC, CODE CV.

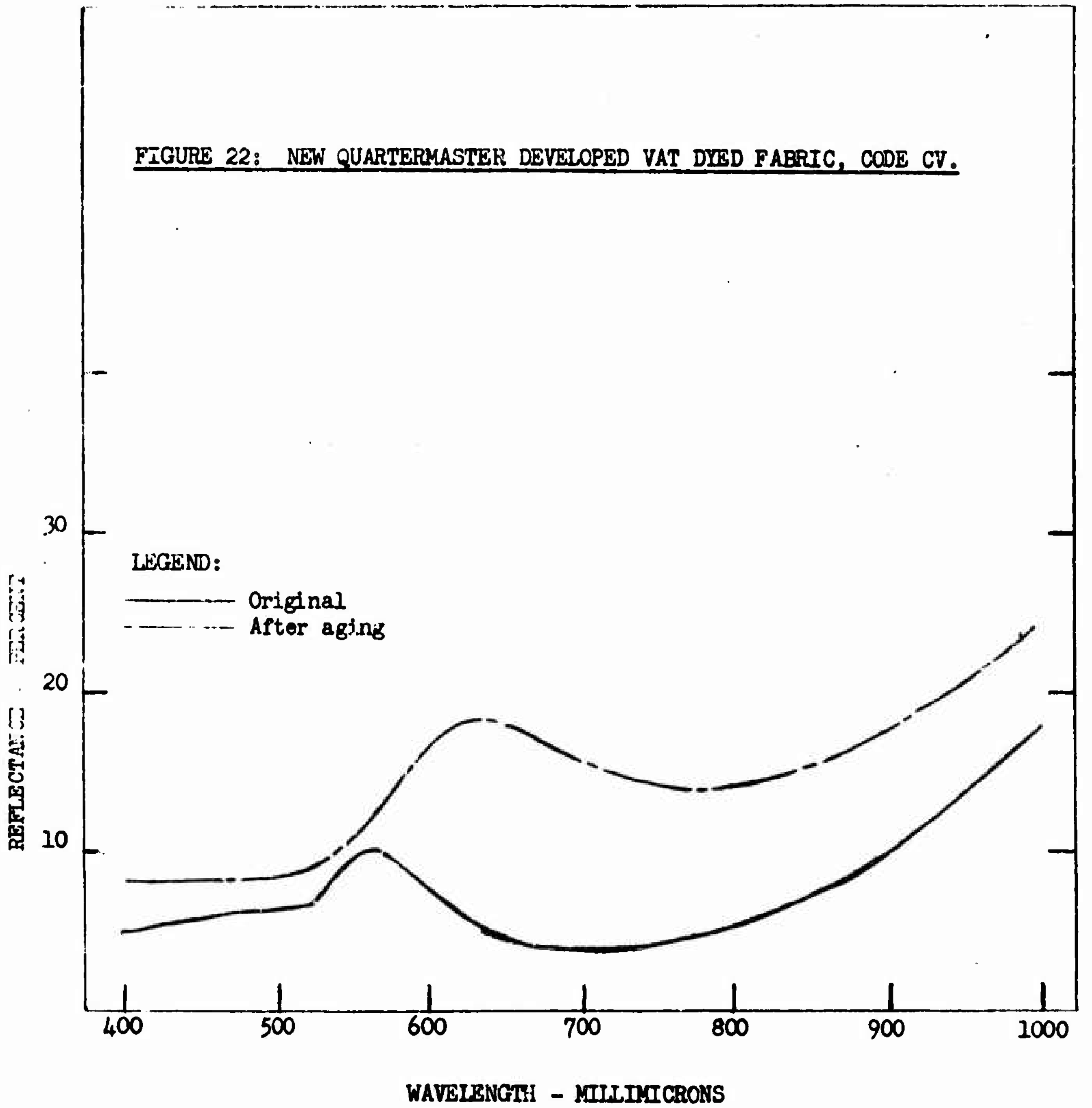
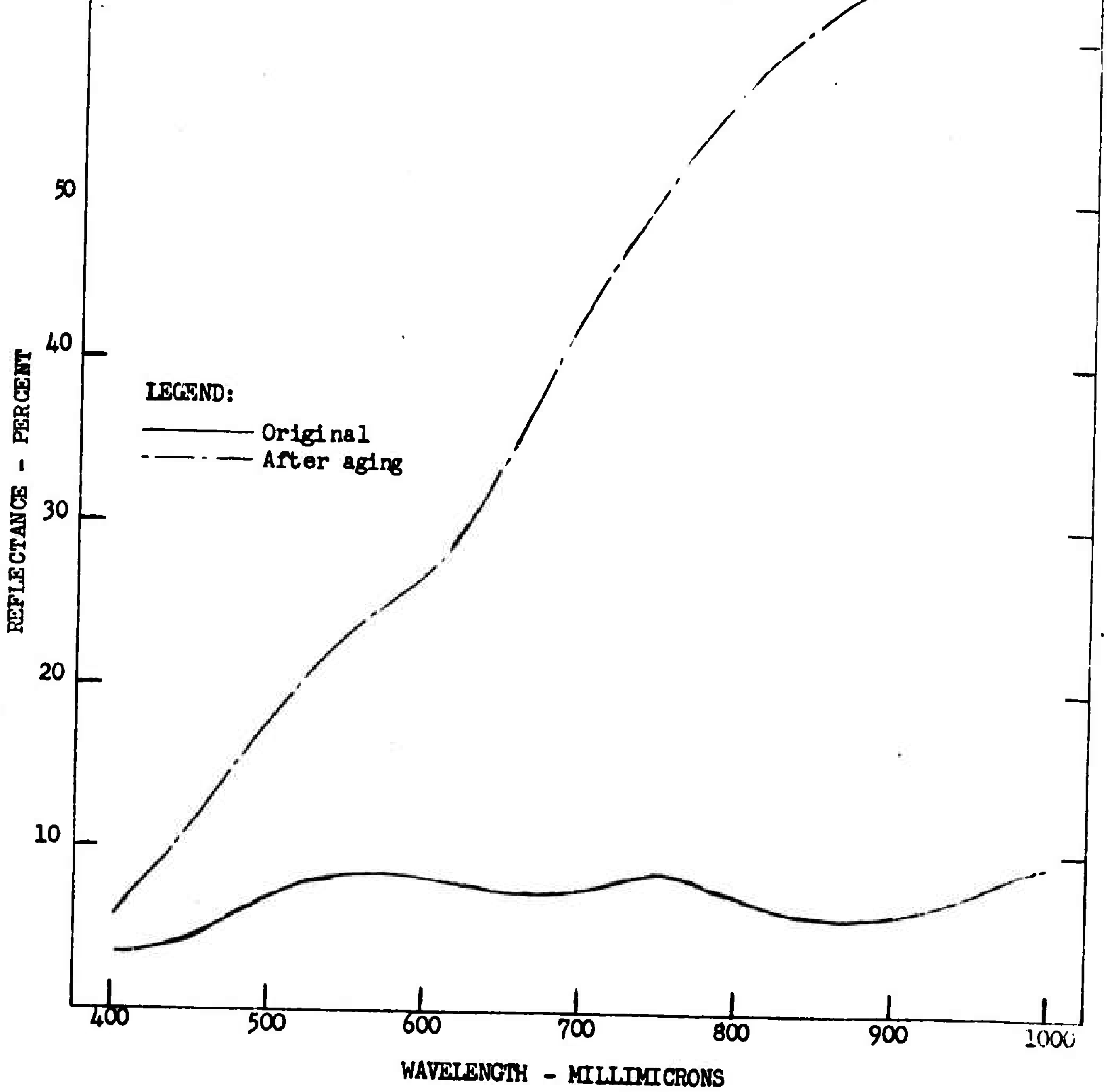


FIGURE 23: SULFUR DYED FABRIC, CODE S.



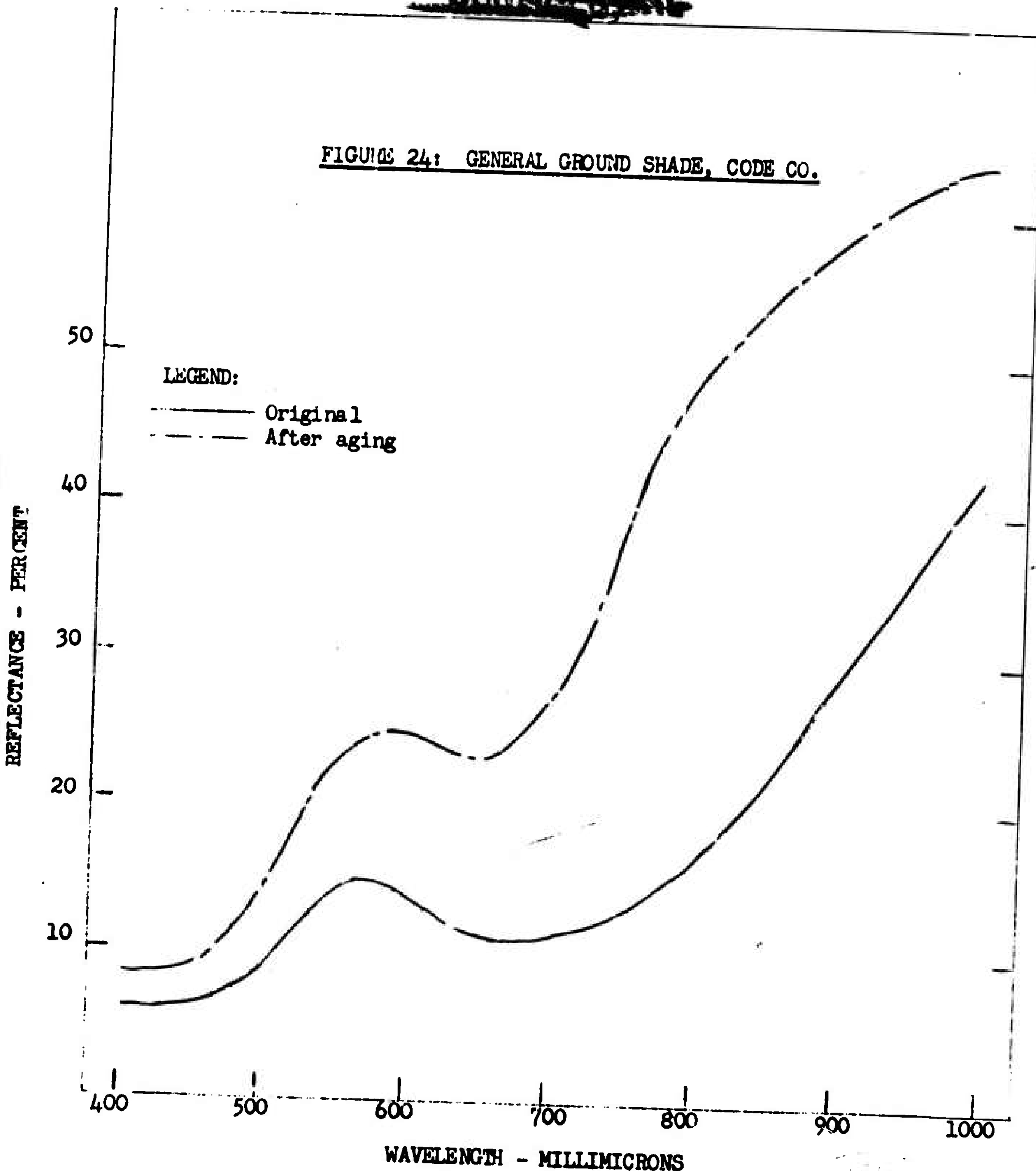


FIGURE 24: GENERAL GROUND SHADE, CODE CO.